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Tammy L. Winfield for the degree of Master of Science in Entomology presented on March 8, 2013.

Title: Assessing Landscape Complexity Using Remotely Sensed and Field Based Measurements: Does Landscape Complexity Drive Leafroller Parasitism Rates on Oregon Caneberry Farms

Abstract approved:

John G. Lambrinos

Landscape heterogeneity is thought to differ among farm management types (i.e. organic and conventional), and this difference is hypothesized to result in variations in pest control by natural enemies. However, it is unclear if these variations in pest control are driven by landscape structure or by farm management practices themselves. Remotely sensed datasets were used to describe the landscape structure surrounding a group of organic and conventional caneberry farms in Oregon and Washington that have different leafroller parasitism rates attributed to farm management type. A finer scale survey was done at one of the farms using the remotely sensed data as well as field surveys. Landscape metrics of diversity, richness and percent non-crop were used to describe the landscapes surrounding the farm fields at scales ranging from 0.05 km to 5.00 km for the large scale study, and 0.05 km to 0.20 km for the fine scale study. In the fine scale study, data on parasitoid species assemblages, diversity, and parasitism rate were collected and analyzed against the calculated landscape metrics spatially and seasonally. The purpose of this study was to quantify effects

of farm management type on habitat structure, effect of habitat structure on leafroller parasitism rate, and to access correlations between landscape metrics calculated at the landscape and field scale. Overall, the farms were embedded in a landscape that was broadly similar, with very few differences in landscape structure occurring between organic and conventional farms. Organic farms had higher vegetation height class diversity at the largest scale compared to conventional farms, while conventional farms had significantly higher percent non-crop area compared to organic farms. There was no significant effect of any of the calculated landscape metrics on parasitism rates. In the field scale study, no correlations were found between habitat metrics and parasitism rates, or between field based metrics and those calculated at the landscape scale. The results of this study suggest that conventional and organic caneberry farms in the Willamette Valley are broadly similar in the habitat conditions they provide parasitoids. This suggests that management changes to pesticide use alone could increase levels of leafroller biological control on conventional farms to levels that are comparable to those seen on organic farms. Our comparisons of the landscape scale and field scale landscape metrics showed no connection, this suggests that direct comparisons cannot be made with these particular metrics at these very different scales. Rather than comparing these types of data, it may be more useful to combine them in order to increase the resolution and predictive power of remotely sensed data for describing landscapes at broad scales.

Assessing Landscape Complexity Using Remotely Sensed and Field Based Measurements: Does Landscape Complexity Drive Leafroller Parasitism Rates on Oregon Caneberry Farms

by

Tammy L. Winfield

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APPROVED:

Major Professor, representing Entomology

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Tammy L. Winfield Author

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CONTRIBUTION OF AUTHORS

Dr. John Lambrinos helped in study design, data analysis and interpretation, writing and manuscript preparation of chapters 2 and 3.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Assessing Landscape Complexity Using Remotely Sensed and Field Based Measurements: Does Landscape Complexity Drive Leafroller Parasitism Rates on Oregon Caneberry Farms

Chapter 1

General Introduction

Ecosystem services provided by natural enemies are extremely valuable to agricultural production. These services are estimated to be worth at least 4.5 million dollars in the U.S. alone (Losey and Vaughn 2006). Parasitoid wasps are a particularly important group of natural enemies in agricultural systems that have the potential to significantly reduce pest populations (Legner and Gordh 1992, Hamilton and Lashomb 1996, Wearing et al. 2012). Unfortunately, many agricultural systems have low abundances of parasitoids or low levels of pest parasitism (Suh et al. 2000, Bianchi et al 2006, Chaplin-Kramer et al. 2011). These observed reductions have been attributed to both the direct negative effects of pesticide use as well as indirect effects associated with the poor habitat conditions for adult parasitoids that result from agricultural practices (Heimpel and Jervis 2005, Thies and Tscharntke 2005, Tscharntke et al. 2005). Farmers could potentially improve conditions for parasitoids through habitat improvements or changes in pesticide use (Landis et al. 2000). However, implementing effective management changes is complicated by the fact that many of the factors influencing the level of biological control provided by parasitoids are known to be scale dependent. For instance, many adult parasitoids require access to floral resources such as nectar and pollen to complete their lifecycle (Heimpel and Jervis 2005). And a number of studies have shown that the abundance of floral resources within or adjacent to crop fields is positively associated with levels of wasp abundance and parasitism (Lee and Heimpel 2005, Lavendero et al. 2005, Berndt et al. 2006, Irvin et al. 2006). However, habitat conditions in the landscape matrix surrounding crop fields can also have a

significant influence on local parasitoid abundance and parasitism rates (Altieri and Whitcomb 1979, Kruess and Tscharntke 1994, Roschewitz et al. 2005, Tscharntke et al. 2005, Lee and Heimpel 2008). As a consequence, the degree to which farmers can influence parasitism levels in their fields through local modifications to their management practices is often far from clear.

A number of studies have documented positive associations between the proportion of semi-natural habitat in a landscape and levels of in-field pest control (Chaplin-Kramer et al. 2011, Veres et al. 2011). These metrics are assumed to correlate with the abundance of resources or habitat conditions required by adult wasps. However, few landscape scale studies have explicitly tested the assumption that this relationship is tied to resource levels available to natural enemies, and recent studies have suggested that management factors associated with agricultural intensification such as levels of disturbance and insecticide use may be the main causes of reduced levels of biocontrol in agricultural landscapes (Veres et al. 2011, Jonsson et al. 2012).

Organic and conventional farms potentially vary considerably in their habitat characteristics. Organic farms often have structurally more complex or diverse vegetation than conventional farms (Bengtsson et al. 2005, Hole et al. 2005, Letourneau and Bothwell 2008, Mader et al. 2005). However, the relationship between farm management practices and vegetation characteristics varies considerably with the taxonomic resolution of the study and the scale of observation. Bengtsson et al. (2005) conducted a meta-analysis of studies comparing biodiversity characteristics of organic and conventional production systems. They found that studies conducted at the field scale reported stronger differences in biodiversity between organic and conventional farms than those conducted at larger landscape scales.

More functionally based habitat descriptions could increase the power to detect relationships between landscape characteristics and parasitoid populations, but traditional methods of collecting these types of data (e.g. field surveys) are time consuming, costly, and result in information that is spatially limited.

However, the increasing availability of remotely sensed data is creating greater opportunities to describe functional habitat characteristics over large region-wide scales (Antonarakis et al. 2011). One form of these increasingly available data sets is high spatial resolution descriptions of vegetation structure derived from LiDAR (Light Detection and Range, Dubayah et al. 2000). Vegetation structure and habitat complexity can directly mediate natural enemy interactions by affecting factors such as dispersal and providing suitable microhabitats. Vegetation complexity can also covary with other resources such as floral abundance (Denno et al. 2005). LiDAR has been successfully used to categorize forest structure, and to calculate mean vegetation heights and maximum tree heights (Dubayah et al. 2000, Lefsky et al. 2002, Antonarakis et al. 2011). LiDAR and other remotely sensed data such as detailed landcover classifications have also been used to create habitat models that predict the occurrences of birds, butterflies, ground and water beetles, and various forest insect species (Goetz et al. 2007, Luoto et al. 2002, Eyre et al. 2003a, b, Chust et al. 2004, Goetz et al. 2007, and Clawges et al. 2008). LiDAR in particular has been used to successfully model beetle and spider abundance and community composition in forests (Muller et al. 2009, Muller and Brandl 2009). Vierling et al. (2011) found that LiDAR derived habit predictors worked as well or better at describing species composition than those collected via field surveys. However, the literature on the use of remotely sensed data for understanding, predicting, and mapping the incidence of insects in agricultural landscapes is largely lacking, and those studies that do exist focus more on insect pests than the conservation of beneficial insects (Riley 1989, Leyequien et al. 2007).

Using remotely sensed data can garner patterns of large scale landscape structure, but it is unclear how these measurements relate to those collected in the field. Field collected data is by definition more site specific and has much finer resolution than remotely sensed data. This study compares the landscape structure surrounding 24 organic and conventional caneberry farms in Oregon and Washington using metrics of landscape structure derived from remotely sensed

data and field data to answer these questions: 1) Do organic and conventional caneberry farms in Oregon differ in landscape structure, 2) Do these calculated landscape structure metrics effect parasitism rates and 3) Do landscape metrics calculated with remotely sensed data relate to those calculated with field data.

Chapter 2

Are rates of leafroller parasitism contingent upon the landscape structure surrounding Oregon caneberry farms?

ABSTRACT

Landscape heterogeneity is thought to differ among farm management types (e.g. organic and conventional), and this difference is hypothesized to result in variations in pest control by natural enemies. This difference is attributed to the ability of parasitoids to benefit from nectar or honeydew derived sugar meals by increasing their life span and fecundity. However, it is unclear if these variations in pest control are mostly driven by landscape structure or by farm management practices. I used two remotely sensed datasets to describe the landscape structure surrounding a group of organic and conventional caneberry farms in Oregon and Washington that have different leafroller parasitism rates attributed to farm management type. Using metrics of landcover and vegetation height richness and diversity, as well as a percent non-crop metric, I described the landscape surrounding these farms at scales ranging from 0.05 km to 5.00 km. The purpose of this study was to determine any effect of farm management type on habitat structure as well as any effect of this habitat structure on leafroller parasitism rate. At larger scales organic farms had higher height class diversity scores. I also found a significant percent non-crop difference between organic and conventional farms at the smallest scales: conventional farms had higher percent non-crop at the 0.05 km and 0.10 km scales. There was no significant effect on parasitism rate for any of the calculated landscape metrics. The results of this study illustrate that conventional and organic caneberry farms in the Willamette Valley are broadly similar in the habitat conditions they provide parasitoids. This suggests that management changes to pesticide use alone could increase levels of leafroller biological control on conventional farms to levels that are comparable to those seen on organic farms.

Keywords: LiDAR, Remote sensing, Landscape heterogeneity, Landcover, Parasitoid, Leafroller

INTRODUCTION

Ecosystem services provided by natural enemies are extremely valuable to agricultural production. These services are estimated to be worth at least 4.5 million dollars in the US alone (Losey and Vaughn 2006). Parasitoid wasps are a particularly important group of natural enemies in agricultural systems that have the potential to significantly reduce pest populations (Legner and Gordh 1992, Hamilton and Lashomb 1996, Wearing, et al. 2012). Unfortunately, many agricultural systems have low abundances of parasitoids or low levels of pest parasitism (Suh et al. 2000, Bianchi et al. 2006, Chaplin-Kramer et al. 2011). These observed reductions have been attributed to both the direct negative effects of pesticide use as well as indirect effects associated with the poor habitat conditions for adult parasitoids that are often associated with agricultural practices (Heimpel and Jervis 2005, Thies and Tscharntke 2005, Tscharntke et al. 2005). Farmers could potentially improve conditions for parasitoids through habitat improvements or changes in pesticide use (Landis et al. 2000). However, implementing effective management changes is complicated by the fact that many of the factors influencing the level of biological control provided by parasitoids are known to be scale dependent. For instance, many adult parasitoids require access to floral resources such as nectar and pollen to complete their lifecycle (Heimpel and Jervis 2005). A number of studies have shown that levels of wasp abundance and parasitism is positively associated with the abundance of floral resources within or adjacent to crop fields (Lee and Heimpel 2005, Lavendero et al. 2005, Berndt et al. 2006, Irvin et al. 2006). Habitat conditions in the landscape matrix surrounding crop fields can also have a significant influence on local parasitoid abundance and parasitism rates (Altieri and Whitcomb 1979, Kruess and Tscharntke 1994, Roschewitz et al., 2005, Tscharntke et al, 2005, Lee and Heimpel 2008). As a consequence, the degree to which farmers can influence

parasitism levels in their fields through local modifications to their management practices is often far from clear.

BIOCONTROL IN PACIFIC NORTHWEST CANEBERRY PRODUCTION LANDSCAPES

Caneberry production is a thriving business in the Pacific Northwest of the United States. Oregon alone accounts for 90% of US blackberry production and 9% of raspberry production, with the bulk of this production coming from the Willamette Valley (Peerbolt 2008). An important contaminant pest in processed caneberries is a leafroller known as the orange tortrix *Argyrotaenia franciscana* (Walsingham) (formerly *Argyrotaenia citrana* Fernald) (Lepidoptera: Tortricidae). Several parasitoid wasps attack orange tortrix; the most common being *Apanteles aristoteliae* (Knight and Croft 1987, Walker and Welter 2004, Bolda et al. 2010). *A. aristoteliae* is a solitary koinobiont (allowing the host to develop while feeding on it) endoparasitoid that is also the dominant parasitoid of leafroller pests in a number of other important crops: citrus, apples, pears, strawberries, and grapes (Basinger 1938, Kido et al. 1981, Coop et al. 1989, Walker & Welter 2004). Some adult parasitoid wasps have been shown to feed as adults on the tissue and hemolymph of their host insects (Jervis and Kidd 1986). However, adult *A. aristoteliae* are not known to host fee; therefore, these wasps likely extend their life spans via nectar feeding (Lightle et al. 2010).

The leafroller parasitoid assemblage appears to provide significant biocontrol of leafrollers in Pacific Northwest caneberry fields. A multi-year study conducted in conventional (i.e. farms that use synthetic pesticides) and organic (farms that do not use synthetic pesticides or are certified organic) caneberry farms found a significant relationship between parasitoid abundance, rates of leafroller parasitism, and overall leafroller abundance within fields (Paul Jepson 2013 pers. com. unpublished data). The biggest apparent cause of field to field variation in parasitism rate was the use of insecticides. Leafroller larvae on organic farms were nearly twice as likely to be parasitized as leafroller larvae on farms under conventional production practices that included the use of broad spectrum insecticides (Paul Jepson 2013 pers. com. unpublished data). However,

the Jepson study did not describe other aspects of local or landscape habitat conditions that potentially varied across the study farms, or explicitly test the degree to which these other habitat factors contributed to local parasitism rates. Indeed, other studies have found that habitat conditions in the surrounding landscape have a much stronger influence on local insect populations than do local management practices (Marino and Landis 1996, Steffan-Dewenter et al. 2002, Weibull and Ostman 2003, Purtauf et al. 2006, Chaplin-Kramer et al. 2011 and references within).

The farm fields in the Jepson study potentially vary considerably in their habitat characteristics. Organic farms often have structurally more complex or diverse vegetation than conventional farms (Bengtsson et al. 2005, Hole et al. 2005, Letourneau and Bothwell 2008, Mader et al. 2005). However, the relationship between farm management practices and vegetation characteristics varies considerably with the taxonomic resolution of the study and the scale of observation. Bengtsson et al. (2005) conducted a meta-analysis of studies comparing biodiversity characteristics of organic and conventional production systems. They found that studies conducted at the field scale reported stronger differences in biodiversity between organic and conventional farms than those conducted at larger landscape scales.

A number of studies have documented positive associations between the proportion of semi-natural habitat in a landscape and levels of in-field pest control (Chaplin-Kramer et al. 2011, Veres et al. 2011). These metrics are assumed to correlate with the abundance of resources or habitat conditions required by adult wasps. However, few landscape scale studies have explicitly tested the assumption that this relationship is tied to resource levels available to natural enemies, and recent studies have suggested that management factors associated with agricultural intensification such as levels of disturbance and insecticide use may be the main causes of reduced levels of biocontrol in agricultural landscapes (Veres et al. 2011, Jonsson et al. 2012). More functionally based habitat descriptions could increase the power to detect relationships between landscape

characteristics and parasitoid populations, but traditional methods of collecting these types of data (e.g. field surveys) are time consuming, costly, and result in information that is spatially limited. However, the increasing availability of remotely sensed data is creating greater opportunities to describe functional habitat characteristics over large region-wide scales (Antonarakis et al. 2011). One form of these increasingly available data sets is high resolution descriptions of vegetation structure derived from LiDAR (Light Detection and Range, Dubayah et al. 2000). Vegetation structure and complexity can directly mediate natural enemy interactions by affecting factors such as dispersal and provisioning of suitable microhabitats. Vegetation complexity has also been shown to covary with other resources such as floral abundance (Denno et al. 2005). LiDAR has been successfully used to categorize forest structure, and to calculate mean vegetation heights and maximum tree heights (Dubayah et al. 2000, Lefsky et al. 2002, Antonarakis et al. 2011). LiDAR and other remotely sensed data such as detailed landcover classifications have been used to create habitat models that predict the occurrences of birds, butterflies, ground and water beetles, and various forest insect species (Goetz et al. 2007, Luoto et al. 2002, Eyre et al. 2003a, b, Chust et al. 2004, Goetz et al. 2007, and Clawges et al. 2008). LiDAR in particular has been used to successfully model beetle and spider abundance and community composition in forests (Muller et al. 2009, Muller and Brandl 2009). Vierling et al. (2011) found that LiDAR derived habit predictors worked as well or better at describing species composition than those collected via field surveys. Unfortunately, the literature on the use of remotely sensed data for understanding, predicting, and mapping the incidence of insects in agricultural landscapes is largely lacking, and those studies that do exist focus more on insect pests than the conservation of beneficial insects (Riley 1989, Leyequien et al. 2007).

OBJECTIVES

The habitat characteristics of the farms in the Jepson study and of Pacific Northwest caneberry production landscapes in general have not been previously described. It is therefore not known to what extent differences in habitat

conditions across farms contribute to the observed differences in leafroller biocontrol provided by parasitoid wasps. Our objectives for this study were to: 1) describe the habitat characteristics of caneberry farms in Oregon and Washington across a range of spatial scales using the 2006 national landcover dataset (NLCD) and a detailed vegetation structure model derived from LiDAR, 2) test whether organic and conventional farms differ in their habitat characteristics across a range of spatial scales, and 3) test whether habitat characteristics explain variation in leafroller parasitism across farms.

MATERIALS AND METHODS

STUDY SITE

Our study sites were 70 raspberry and blackberry fields in Oregon and Washington that varied in their management practices (Figure 1). These farms were a mix of certified organic and conventional farms. The conventional farms range in the types of pesticides they sprayed (e.g. broad spectrum vs. narrow spectrum) and the amount or frequency of sprays. For our purposes we simply categorized theses farms as organic (these farms are certified organic or do not use synthetic pesticides) or conventional (these farms spray synthetic pesticides). All the fields were located within the Willamette Valley Ecoregion. This region contains a rich mix of agricultural, urban, and natural landscapes and has a mild climate that is cool and wet in the winter and warm and relatively dry in the summer.

ASSESSMENT OF LEAFROLLER PARASITISM

The Jepson et al. (2013) team assessed levels of leafroller pest abundance and parasitism on the 70 study fields from 2005-2008. They conducted field surveys for leafrollers using timed visual searches. Any leafrollers encountered during the surveys were brought back to a lab in Corvallis and kept on an artificial diet until they pupated or until parasitoids were reared out. Both leafrollers and parasitoids were identified to species. For each field that leafrollers were collected in, a yearly and a four year mean parasitism rate was calculated (Jepson pers.com. 2013).

For our analysis we grouped fields that were located within 1 km of each other. This is because at this scale neighboring fields often had broadly overlapping landscape neighborhoods and could not be treated as independent with respect to landscape neighborhood. Grouping fields in this way resulted in 23 farms. We call these groups farms since in most cases the fields did indeed belong to the same farm. In one case, multiple growers had fields either adjoining

each other, or less than the 1 km distance and we considered these fields as one farm (Figure 2). We averaged the yearly field leafroller abundance and parasitism rate reported by Jepson et al. (2013) by farm.

HABITAT CHARACTERIZATION

I assessed the habitat characteristics associated with each field using a landcover model derived from Landsat data and a vegetation canopy model derived from LiDAR. All habitat analyses of landcover and LiDAR data were done within a GIS database using ArcGIS 10.0 (ESRI 2011).

LIDAR AND LANDCOVER DATA

For the Willamette Valley portion of the study area I used a 2009 LiDAR dataset that was collected and processed by Watershed Sciences Inc. for the Oregon Department of Geology and Mineral Industries (DOGAMI 2009). For the Columbia river/Portland area portion of the study area, I used a LiDAR dataset created by the Puget Sound LiDAR consortium (PSLC 2005). These datasets were delivered in the form of "bare earth" and "top surface" returns; a vegetation canopy layer was created from these returns using the raster calculator tool in ArcGIS 10.0 (ESRI 2011). The resolution for both LiDAR datasets was ± 3 meters, and vertical accuracy was ± 37 cm. 28 of the Jepson et al. farms were outside of the available LiDAR data coverage and therefore did not have vegetation structure descriptions calculated for these farms (Figure 4). As a way of classifying the structural complexity of vegetation canopy height, I reclassified the LiDAR canopy layers into 18 separate height classes; each class representing a specific height range (Table 1). Because there are potentially more vegetation types of interest to us at lower vegetation heights (e.g. shrubs, weedy vegetation, hedgerows), I made our classification scheme more detailed at lower heights by making the classes represent smaller ranges of heights. Land Cover data were acquired using the 2006 National Land Cover Database (NLCD) via the multi-resolution land characteristics consortium (Fry et al 2011). The NLCD is a 20 class land cover scheme created from Landsat Enhanced Thematic Mapper satellite imagery that is available for the conterminous United States (Table 2).

HABITAT DESCRIPTORS

I assessed habitat at different distances from the center of each field. I created 6 non-overlapping circular buffers centered on each field with radii of: 0.05, 0.10, 0.50, 1.50, 2.50 and 5.00 km (Figure 3). For each buffer on each farm I calculated the following habitat descriptors based on the landcover and vegetation canopy model layers:

1. Proportion of non-crop habitat. Mean percent non-crop landcover was defined as any landcover type that was not associated with human development or agricultural production (NLCD codes 21-24 and 81-82, Table 2).

2. Landcover class richness and diversity. Landcover richness was calculated by summing the number of distinct landcover types within each buffer. Landcover diversity was calculated using Simpson's index (D), where the abundance of each landcover class was estimated as its proportional areal coverage within each buffer. I chose Simpson's index because it is less likely to be skewed by rare habitats since the index is less sensitive to category richness compared to other indices (Magurran 2004). For analysis and presentation I transformed D to -lnD so that our diversity index had the more intuitive property of increasing as the diversity of the sample increases. Using the negative logarithm can also help to minimize variance issues that occur when using other transformations (Magurran 2004).

3. Vegetation structural complexity. Vegetation complexity was estimated by calculating both richness and diversity of vegetation height classes within each buffer. Height class richness was calculated by summing the number of distinct height class categories within each zone. Height class diversity was calculated using Simpson's index (D) where the abundance of each height class was estimated as its proportional areal coverage within each buffer. I transformed the Simpson index values as described above for landcover class diversity.

ANALYSIS

I used a general linear model procedure to test for differences in landscape habitat characteristics between organic and conventional farm types across the six spatial scales. The model consisted of farm type (two levels) and spatial scale (six levels) as categorical factors, a farm type x spatial scale interaction term, and the five habitat metrics as separate response variables. Pairwise comparisons between farm types at a given spatial scale were made using Tukey's adjustment for multiple comparisons. The habitat metrics used in this study have been shown to be highly correlated in some cases (Thies and Tscharntke 1999, Steffan-Dewenter et al. 2002, Roschewitz et al. 2005). I described the correlation structure of the measured habitat variables using simple correlation coefficients. Percent non-crop was arcsine square-root transformed for all analyses.

I tested the individual effect of each of the habitat variables on parasitism rate within each farm across each of the six spatial scales using linear regression. In the regression models the habitat variables were the independent variables and mean four year percent leafroller parasitism per farm was the dependent variable. Since I knew that farm type had a significant effect on parasitism rate (Jepson pers. com. 2013), I also tested for the influence of the habitat variables on parasitism rate using a general linear model that included farm type as a factor. Percent leafroller parasitism was arcsine square-root transformed for all analyses. All statistical tests were run using SYSTAT 12 (SYSTAT 12, SYSTAT software Inc. 2007).

RESULTS

HABITAT CHARACTERISTICS AS A FUNCTION OF FARM TYPE AND SPATIAL SCALE

The measured habitat variables were broadly correlated with each other, although the strength of these relationships varied for each variable pair and across spatial scales (Table 3).

Agricultural landcover types dominated the landscapes of both organic and conventional farms regardless of spatial scale. The dominant landcover types surrounding both organic and conventional farms were pasture/hay (class 81) and cultivated crops (class 82). Organic and conventional farms were also broadly similar in other aspects of their habitat landscapes. Across all scales mean landcover class diversity (LCCD) and mean landcover class richness (LCCR) were not significantly different between organic and conventional farms (Table 5). Both metrics increased as scale increased (Figure 5). LCCD ranged from a low of 0.79 ± 0.38 to a high of 1.39 ± 0.53 on conventional farms and a low of 0.53 ± 0.45 to a high of 1.51 ± 0.37 on organic farms (Table 4). The lowest LCCD scores were associated with organic farms at the 0.05 km scale. These farms at this scale had a high proportion of their landcover occupied by human development (classes 21, 22, 23, and 24) and crops (classes 81 and 82). The highest LCCD scores were also associated with organic farms but at the 5km scale. The landscapes of these farms at this scale included all the landcover types encountered in this study (Table 2), although their overall landcover was still dominated by crop types.

Percent non-crop vegetation differed significantly between organic and conventional farms at the smallest scales. There was an effect of farm type as well as scale and a significant interaction between farm and scale (Table 5). Conventional farms had higher percent non-crop than organic farms at the 0.05 km scale (Tukey's pairwise comparison $p = 0.010$, d.f. = 1) and at the 0.10 scale (Tukey's pairwise comparison $p = 0.004$, d.f. = 1). At the 0.05 km scale, the area

around conventional farms was comprised of 67% crop type landcover classes, while the area surrounding organic farms was comprised of 80% crop type landcover classes. Conventional farms also had higher percentages of woody wetlands and herbaceous emergent wetlands at this scale than organic farms.

Organic farms also had higher mean height class diversity (HTCD) than conventional farms at the 5.00 km scales (Table 5, Tukey's pairwise comparisons $p = 0.029$, d.f. = 1). Mean height class diversity of organic farms was also greater than conventional farms at the 2.5 km scale, but this difference was not significant (Table 5, Tukey's pairwise comparisons $P = 0.064$, d.f. = 1). Height class richness did not differ between organic and conventional farms at any scale (Table 5). Height class richness increased with spatial scale, but height class diversity was scale invariant (Figure 5). The lowest HTCD scores were associated with conventional farms at the 5 km scale. These farm landscapes were composed almost completely of height class 1 (0.15 - 0.30 m) with very small percentages of other height classes. The highest HTCD scores were associated with organic farms also at the 5.00 km scale. These high diversity scores were made up of 50% or less of height class 1 and had higher percentages of the height classes 2, 3, 9, 10, 11 than the low diversity farms.

EFFECT OF LANDSCAPE HABITAT VARIABLES ON LEAFROLLER PARASITISM

Habitat variables accounted for almost none of the observed variation in leafroller parasitism rate (Table 6). This was true for both the simple linear regression models conducted for each habitat variable at each spatial scale, as well as for the general linear models that included farm type as a factor. The one exception was a significant but weak correlation between height class diversity and parasitism rate at the 0.50 km scale.

CONCLUSIONS AND DISCUSSION

The organic and conventional caneberry farms examined in this study were very similar in habitat composition across a range of spatial scales. It is possible that these farms are embedded in landscapes with very similar levels of structural complexity, which might impede ability to detect differences between farm types. In a number of studies differences in abundance and richness of weedy plants and insects between organic and conventional farms were attributed to the landscape structure that farms were located in, rather than farm management (Roschewitz et al. 2005, Rudolf & Smith 2010). In fact, Rudolf and Smith (2005) found it more difficult to detect differences in bee diversity between these two farm types when the farms were located in more homogenous or simple landscapes. Other studies that have found no differences in abundance or diversity of insects or plants between organic and conventional farms have also attributed this to landscape structure rather than farm management type (e.g. Andersen and Eltun 2000, Weibull et al. 2003). For example, Weibull et al. (2003) found no difference between richness and abundance of plants and butterflies, or landscape heterogeneity that could be attributed to farm management. Rather, they determined that these groups were more affected by small scale landscape heterogeneity or by measures of perimeter to area ratios of field margins (Weibull et al. 2003). In studies that do find differential effects of management types, scale seems to play an important role. A meta-analysis by Bengtsson et al. (2005) determined that significant differences in species richness and abundance between organic and conventional farms were more marked at smaller scales that did not take the larger landscape into account (e.g. at the plot or single field level), and that results from studies done at larger scales (e.g. paired farms in similar landscapes) were more driven by landscape composition than farm management.

Most studies have been done in annual systems, which inherently have higher levels of disturbance than perennial systems. Results from experiments in these fields might be very different from those done in perianal systems. In those few experiments done in perennial cropping systems, (e.g. olives, apple, pear, and cherry orchards) the same or similar results were found (Boccaccio and Ruggero 2009, Pfannenstiel et al. 2012). Therefore, the similarity of these results is likely robust across cropping systems.

Comparing results of landscape metrics from different studies is fraught with issues. Differences of scale (i.e. grain and extent of study area) can cause loss of information and rare groups can be lost at coarser resolutions (Turner et al. 1990). Also, diversity values from different taxonomic groups may not be correlated (Roschewitz et al. 2005). With these caveats I will attempt to compare our calculated landscape metrics with a few other studies in order to estimate how similar or dis-similar our study system might be to these other study systems. This was difficult to do, not only because of the issues stated above, but because most studies did not provide the raw diversity values used in their analyses. Woltz et al. (2012) conducted a study in the Mid-West U.S. to determine the effects of landscape composition and management on biocontrol of a pest aphid. They used the same diversity index and transformation (Simpsons D, -lnD) as our study, but these values were calculated using a 22 land cover classification scheme that was created for their specific study area. Therefore comparisons may not be valid. The broader category of percent natural area, which might more closely correspond to our percent non-crop metric, was also calculated. The percentage of semi-natural habitat in the Woltz et al. (2012) study ranged from 3 to 79% at the 2.00 km scale. Our percent non-crop values (12 to 50%) at the similar scale of 2.50 km fall within that range and our values for percent non-crop at the 1.50 km scale also find similar agreement (2 to 47%). Gardiner et al. (2009) also did a study using a similar landcover classification scheme specific to their study system (corn and soybean crops in the Mid-West U.S.). The percent non-crop values from this study were also similar to ours: at the 3.50 km scale, Gardiner et

al.'s study sites had a range of 1 to 47% non-crop area, while our study sites at the 2.50 scale had non-crop areas of 12 to 50%. However, the resolutions of the datasets are very different and direct comparisons like these might not be valid. Our percent non-crop calculations are at a 30 m resolution while the aforementioned studies used orthophotos at a resolution of 3 m. If I were to analyze percent non-crop at finer resolutions (e.g. 3 m) I would likely include more landcover types and see a change in our estimations of percent non-crop.

This study focused on landscape scale metrics of habitat complexity. However, habitat variables at finer spatial and taxonomic resolutions could be strongly influenced by farm management practices. For instance tillage patterns and other within field disturbance regimes can strongly influence plant community composition at the local field scale (Anderson 1990, Tscharntke 2005). Using datasets that have higher thematic resolution might explain the landscape in more detail and potentially result in different results. For example, a landcover dataset like Oregon GAP vegetation (2010) has a significantly higher thematic resolution than the NLCD dataset (155 vs. 20 total landcover classes). As an added potential benefit, this dataset is specific to Oregon and to our region in general.

The variation in habitat characteristics measured in this study explained little of the variation in leafroller parasitism on farms. Instead, farm practices that are unrelated to these habitat metrics seem to drive the observed differences in parasitism levels. A likely driver is the heavy use of insecticides, many of which are relatively broad spectrum, on the conventional farms included in this study (Jepson pers. comm. 2013). A number of studies have documented the strong impacts that pesticide use can have on parasitoid populations (Brunner et al. 2000, Desneux et al. 2007, Rebek and Sadof 2003). These impacts are often so strong that landscape structure effects can be hidden (Veres et al. 2011). However, a number of other studies have demonstrated that landscape scale habitat factors do have a strong influence on insect populations and levels of pest control at the farm and field scale (Veres et al. 2011). Disentangling the relative importance of

factors influencing the level of biocontrol in particular landscapes is complicated by the fact that many factors associated with agricultural intensification co-vary in space or time (Gabriel et al. 2006, Kremen et al. 2007, Boutin et al. 2008, Fahrig et al. 2011). Schmidt et al. (2006) used both the factors of farm management practices and landscape diversity to show that spider diversity was more affected by large scale landscape diversity more than farm management practices.

It is possible that other habitat variables that were not measured in this study have stronger influences on parasitoid populations and levels of parasitism. It is presumed that broad landcover classifications and vegetation structure relate to resources required by adult parasitoids, such as nectar, or influence parasitoid behavior, but few landscape scale studies have explicitly tested this assumption (Veres et al. 2011, Jonsson et al. 2012). Teasing apart the effects of farm management and diversity is difficult for many reasons. Biodiversity is affected by multiple variables and may respond differentially depending on the scale of the analysis. This in turn can lead to difficulty comparing results between scales or between studies (Turner et al. 1989, Boccacio 2009). Insect biodiversity is affected by the types of habitats that make up the landscape heterogeneity (e.g. plants that are suitable or non-suitable nectar resources). Connecting these landcover or height classes with their suitability as habitat for specific insects might help define more explicit effects of plant heterogeneity on specific insects. Field size is another factor that might affect diversity; however, field size might be constrained or related to the complexity of the landscape the farm is embedded in (Letourneau and Bothwell 2006). Other studies have paired farms by size and by complexity of landscape to account for these potentially confounding effects. Because this particular study was done post-hoc, and I did not have a hand in choosing these farms, I did not have the ability to pair our farms as those studies have done.

The abundance and parasitism rate at the field scale can be strongly influenced by highly dynamic and variable patterns of resource supply driven by management practices. Plant community composition, total floral resource levels,

and phenology can be influenced by management practices such as tillage, inter-row management, and irrigation (Russell 2013, Kreman et al. 2007). Local in-field manipulations of these resources have been shown to influence parasitoid abundance and foraging behavior within fields (Carvalherio 2012, Isaacs et al. 2009, Landis et al. 2000). These habitat conditions are at a finer scale than this study. Given those limitations, the results of this study suggest that conventional and organic caneberry farms in the Willamette Valley are broadly similar in the habitat conditions they provide parasitoids. This suggests that management changes to pesticide use alone could increase levels of leafroller biological control on conventional farms to levels that are comparable to those seen on organic farms. Knowing this information can be a powerful tool to incentivize farmer action and to focus outreach efforts. In other landscape contexts and farming systems local scale habitat improvements may be more important. In still others, increasing biological control could be constrained by the large scale landscape contexts in which individual farms are embedded. Unfortunately, much of the information required to provide such specific recommendations is currently lacking, partly because gathering the necessary context specific information is time consuming.

While higher biodiversity may increase parasitoid or predator abundance, these increases do not always result in improved pest control. The flora that make up the landscape may or may not be appropriate as food or nest site, and thus might not be used by insects. Future research should include attempts to link landscape patterns to functional diversity of both plants (as they relate to insects) and insects (as they relate to pest control). Quantifying spatial heterogeneity is an important step in connecting ecological patterns to processes (Turner et al. 1989, Turner 1990). However, this requires quantifying landscape structure over spatially extensive areas. The use of remotely sensed data could allow landscape structure to be derived at large scales, potentially with low error. Coupling this information with strategically placed field based measurements or datasets with finer thematic resolution (e.g. Oregon GAP vegetation) could help increase the

resolution of the datasets. Field surveys that have been done previously on a sample of these farms could be used in conjunction with the LiDAR and GAP vegetation data to make a spatially explicit dataset that better explains functional floral abundance for the Willamette Valley. This type of data could be used to explicitly connect landscape patterns to insect driven processes like pest control.

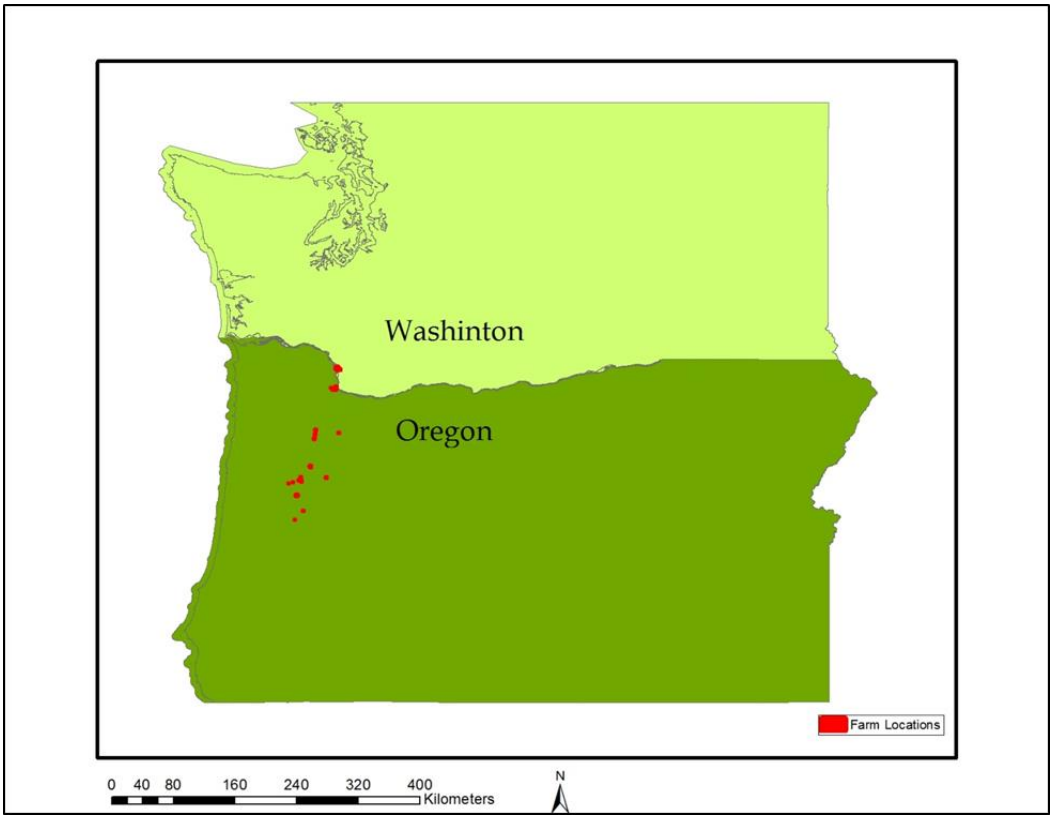

Figure 1. Location of caneberry farms used in this study.

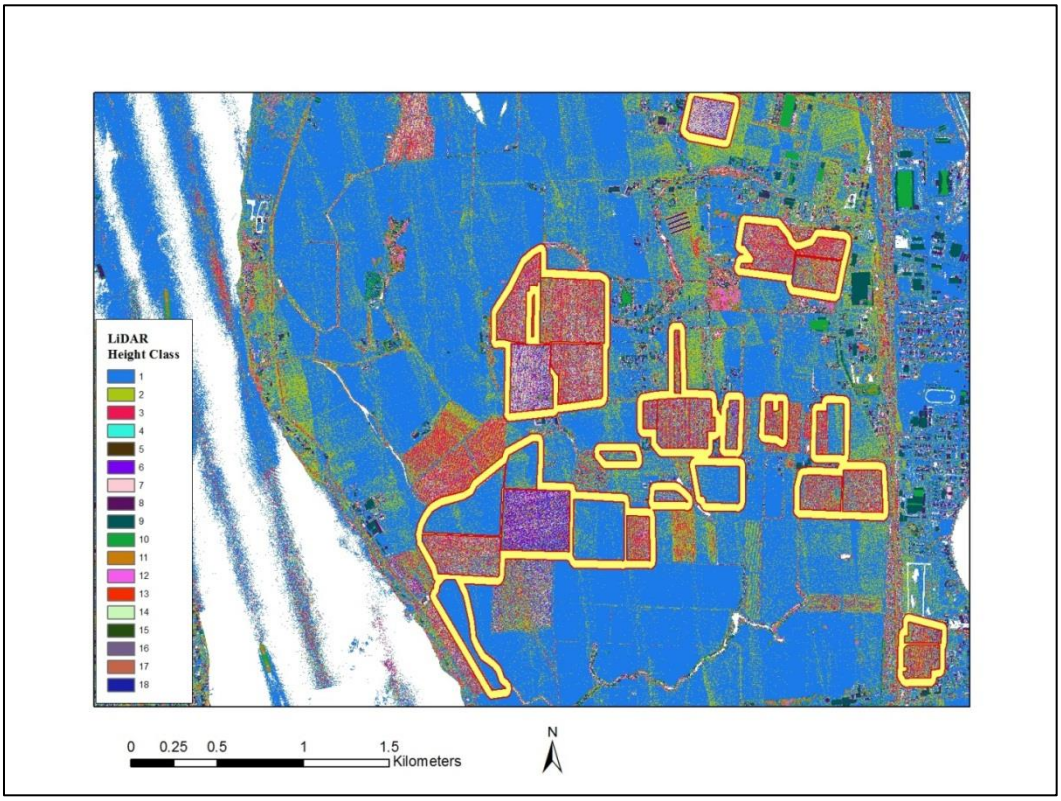

Figure 2. In this study a farm was defined as a group of fields that were within 1 km of each other. The example in this figure is a group of fields located in Washington that are 1 km or less apart and therefore were merged together and considered a single farm.

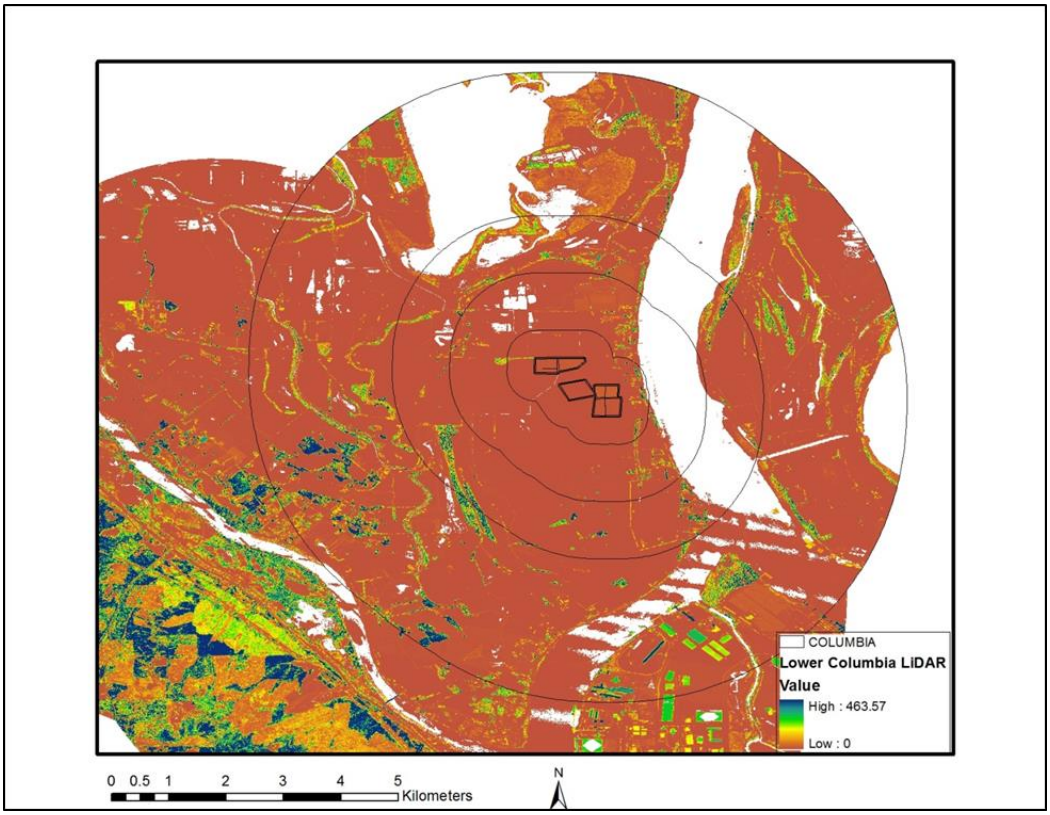

Figure 3. Habitat characteristics for each field were measured from landcover and LiDAR layers at differing distances from the fields. I created six non-overlapping circular buffers with radii of 0.05, 0.10, 0.50, 1.50, 2.50 and 5.00 km.

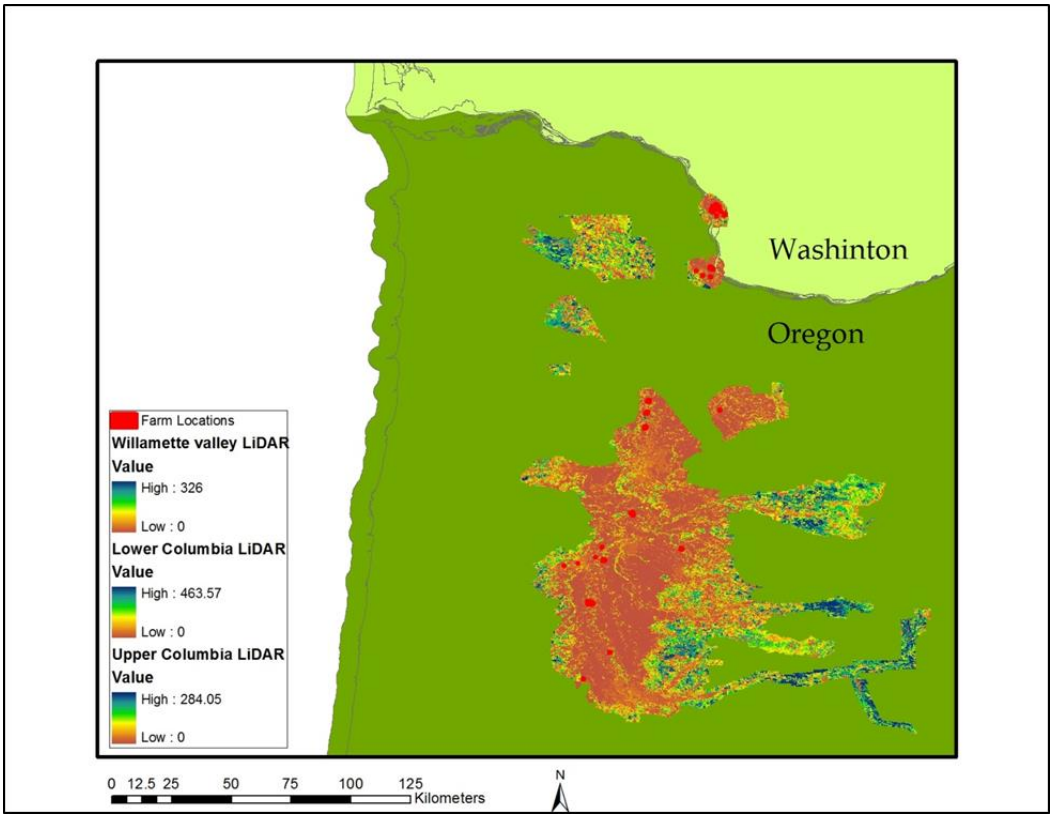

Figure 4. Spatial extent of the two LiDAR datasets used in the study: the upper and lower Columbia layers are from the Puget Sound LiDAR Consortium (PSLC 2005) and the Willamette Valley layer is from the Oregon Department of Geology and Mineral Industries (DOGAMI 2009).

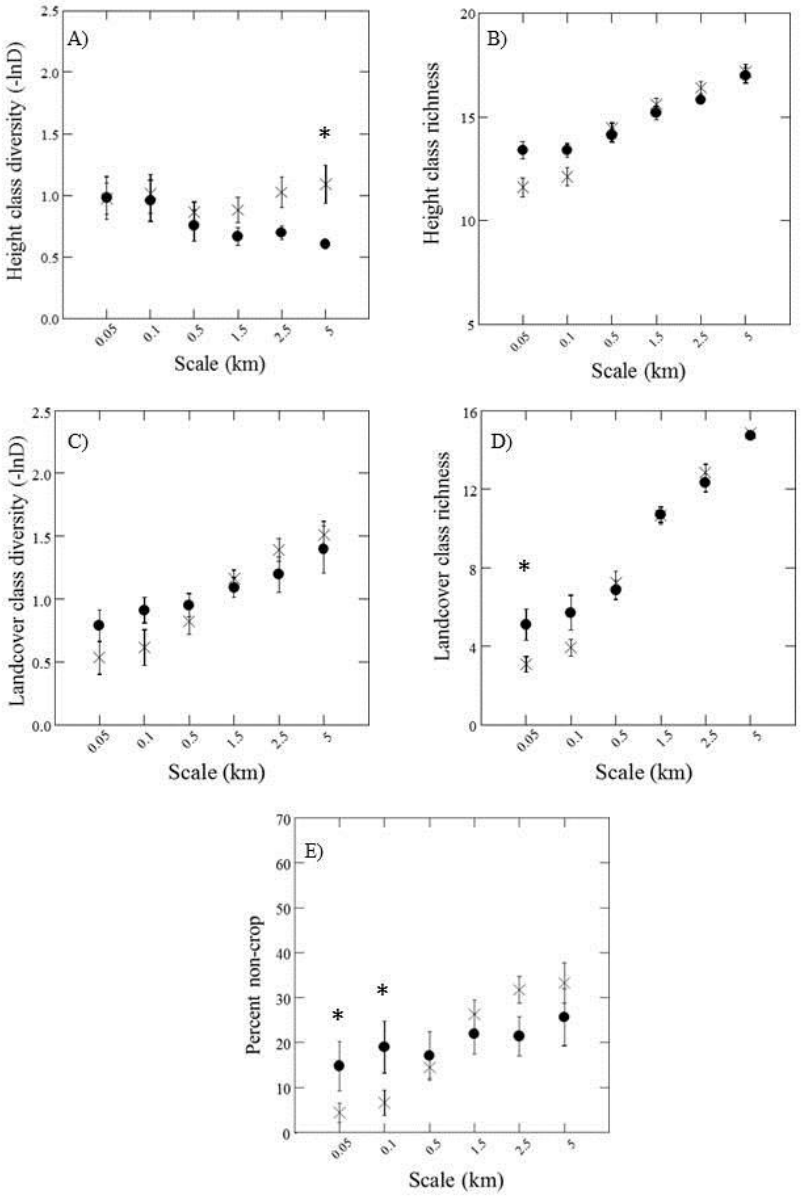

Figure 5. Effects of scale and farm type on landscape descriptor variables A) Mean Landcover class diversity (-lnD). B) Mean height class diversity (-lnD) C) Mean landcover class richness D) Mean Height class richness E) Mean percent non-crop Values are means ±SE. For landcover class diversity and percent non-crop, N= 9 for conventional farms and 13 for organic farms at all scales. For height class diversity, N=9 for conventional farms and 13 for organic farms at scales 0.05 to 2.50km and N= 5 for conventional farms and 11 for organic farms at the 5km scale. This is due to the largest buffers of some farms falling outside of the LiDAR extent. * denote significant differences between organic and conventional farms.

Table 1. Vegetation canopy height class categories used in this study. The vegetation canopy model was derived from two LiDAR datasets. As a way of classifying the structural complexity of vegetation canopy height, I reclassified the LiDAR canopy layers into 18 separate height classes; each class representing a specific height range. Because there are potentially more plants of interest to us at lower vegetation heights (e.g. shrubs, weedy vegetation, hedgerows), our classification scheme is more detailed (e.g. more classes) at lower heights.

Height range (meters)	**Height Class**
0.15 - 0.30	1
0.30 - 0.61	2
0.61 - 0.91	3
0.91 - 1.22	4
1.22 - 1.52	5
1.52 - 3.05	6
3.05 - 4.57	7
4.57 - 9.14	8
9.14 - 15.24	9
15.24 - 22.86	10
22.86 - 30.48	11
30.48 - 38.10	12
38.10 - 44.20	13
44.20 - 50.29	14
50.29 - 56.39	15
56.39 - 68.58	16
68.58 - 85.34	17
85.34 – max height	18

Table 2. The national landcover dataset (NLCD) landcover types encountered in the study area. The NLCD classifications were used to calculate landcover class richness and diversity and percent non-crop landcover for each farm. Percent non-crop landcover included all cover types except those specified as developed (21-24) or as crop types (81 and 82).

NLCD Code	NLCD Cover type
11	Open water
12	Perennial ice/snow
21	Developed open space
22	Developed low intensity
23	Developed medium intensity
24	Developed high intensity
31	Barren land
41	Deciduous forest
42	Evergreen forest
43	Mixed forest
52	Shrub/scrub
71	Grassland/Herbaceous
81	Pasture/hay
82	Cultivated crops
90	Woody wetlands
95	Emergent herbaceous wetlands

Table 3. Pearson correlation coefficients for landscape variables at the smallest and largest scales. Height class richness = HTCR; Height class diversity = HTCD; Landcover class richness = LCCR; Landcover class diversity=LCCD; Percent non-crop =%NC. Significant correlations are bolded.

Pearson Correlation Matrix for smallest scale (0.05km)					
	HTCR	HTCD	LCCR	LCCD	%NC
HTCR	1.000				
HTCD	0.110	1.000			
LCCR	0.546	0.032	1.000		
LCCD	0.561	0.406	**0.667**	1.000	
%NC	**0.650**	0.383	0.448	0.484	1.000

Pearson Correlation matrix for largest scale (5.00km)					
	HTCR	HTCD	LCCR	LCCD	%NC
HTCR	1.000				
HTCD	0.333	1.000			
LCCR	0.048	0.202	1.000		
LCCD	0.357	**0.803**	0.365	1.000	
%NC	0.324	**0.868**	0.396	**0.820**	1.000

Table 4. Habitat characteristics of conventional and organic caneberry farms across six spatial scales in the Willamette Valley of Oregon. Values are means ±SE. For landcover diversity and percent non-crop, N= 9 for conventional farms and 13 for organic farms at all scales. For height class diversity, N=9 for conventional farms and 13 for organic farms at scales 0.05 to 2.50 km. Because some of the larger buffers fell outside of the LiDAR extent, N= 5 for conventional farms and 11 for organic farms at the 5 km scale. Non-crop includes landcover types that are not associated with crops, developed areas, or open water.

Buffer (km)	Farm type	Mean Height Class Richness	Mean Height Class Diversity (-lnD)	Mean Landcover Class Richness	Mean Landcover Class Diversity (-lnD)	Mean Percent Noncrop
0.05	Conventional	13.40 ± 0.40	0.98 ± 0.16	5.10 ± 0.74	0.79 ± 0.38	14.81 ± 5.15
	Organic	11.61 ± 0.45	0.97 ± 0.12	3.08 ± 0.34	0.53 ± 0.45	4.42 ± 2.05
0.10	Conventional	13.40 ± 0.31	0.96 ± 0.16	5.70 ± 0.84	0.91± 0.31	18.99 ± 5.43
	Organic	12.11 ± 0.42	1.01 ± 0.15	3.92 ± 0.40	0.61 ± 0.49	6.63 ± 2.73
0.50	Conventional	14.13 ± 0.31	0.75 ± 0.12	6.87 ± 0.45	0.95± 0.26	18.52 ± 4.96
	Organic	14.46 ± 0.25	0.87 ± 0.08	7.25 ± 0.54	0.83± 0.36	14.46 ± 2.25
1.50	Conventional	15.19 ± 0.30	0.67 ± 0.07	10.71 ± 0.37	1.09 ± 0.22	21.92 ± 4.23
	Organic	15.62 ± 0.27	0.92 ± 0.10	10.64 ± 0.41	1.16 ± 0.24	26.28 ± 3.04
2.50	Conventional	15.80 ± 0.13	0.70 ± 0.05	12.33 ± 0.44	1.46± 1.09	21.41 ± 4.12
	Organic	16.41 ± 0.30	1.02 ± 0.12	12.86 ± 0.39	1.39± 0.31	31.73 ± 2.86
5.00	Conventional	17.00 ± 0.41	0.61 ± 0.03	14.72 ± 0.15	1.39 ± 0.53	25.64 ± 5.92
	Organic	17.17 ± 0.30	1.09 ± 0.15	14.85 ± 0.10	1.51 ± 0.37	33.31 ± 4.32

Table 5.General linear model results for effect of Farm type and spatial scale on five habitat variables. There were significant effects of farm type on height class diversity at larger scales. Scale itself had a significant effect on height class richness and landcover class richness and diversity, with interactions between farm type and scale for the richness variables. There were significant effects of scale and an interaction of scale and farm type for percent non-crop. *** for P<0.001, ** for P<0.01 and * for P<0.05. NS for non-significant P>0.05

	DF	F	P
Height class richness			
Farm Type	1	1.54	NS
Scale	5	51.88	***
Farm type x Scale	5	4.49	***
Height class diversity			
Farm Type	1	7.16	**
Scale	5	1.02	NS
Farm type x Scale	5	0.91	NS
Landcover class richness			
Farm Type	1	2.97	NS
Scale	5	170.30	***
Farm type x Scale	5	2.9	**
Landcover class diversity			
Farm Type	1	0.56	NS
Scale	5	15.32	***
Farm type x Scale	5	1.66	NS
Percent non-crop			
Farm Type	1	0.110	NS
Scale	5	8.552	***
Farm type x scale	5	3.051	**

Table 6. General linear model regression coefficients across all scales testing effect of habitat variables on parasitism rate. Variables accounted for almost none of the observed variation in leafroller parasitism. Bolded values are significant.

	Scale (km)					
Landscape variable	0.05	0.1	0.5	1.5	2.5	5.0
Height class richness	0.017	0.001	0.142	0.095	0.032	0.030
Height class diversity	0.063	0.013	**0.179**	0.110	0.139	0.139
Landcover class richness	0.042	0.044	0.032	0.132	0.002	0.008
Landcover class diversity	0.001	0.038	0.007	0.025	0.000	0.004
Percent non-crop	0.013	0.066	0.000	0.036	0.010	0.002

Chapter 3

ARE RATES OF LEAFROLLER PARASITISM RELATED TO FLORAL RESOURCES AND HABITAT STRUCTURE AT THE FIELD SCALE?

ABSTRACT

Nectar from floral resources in the landscape can increase the longevity and fecundity of parasitoid wasps, potentially resulting in increased pest control. However, this effect may depend on the spatial arrangement of these resources and whether or not the resources are accessible by small wasps. Determining what resources are in the landscape using field measurements is time consuming and the resultant measurements are often spatially limited. Using high resolution remotely sensed data to quantify the landscape may reduce these limitations. The purpose of this research was to determine the structure of the landscape surrounding caneberry fields using metrics of diversity and richness calculated from both field and remotely sensed based data, and to determine how these metrics relate to each other as well as to the on farm parasitoid assemblage. I conducted bi-weekly surveys of plant and insect populations from April-October 2011. I calculated percent bloom cover, plant diversity, and plant richness in caneberry fields and in four buffers of radii: 20, 50, 100, and 200 meters centered on the fields. To calculate these metrics using remotely sensed data, I used a LiDAR derived vegetation canopy layer for the Willamette Valley to describe vegetation complexity via height class diversity and richness. I also calculated the nearest distance from caneberry rows to on farm hedgerows to determine if parasitism rate is contingent upon hedgerow location. To quantify the resources explicitly in terms of availability to parasitoids, I classified the on farm floral resources using a binary metric: 1 for plants that were either a priori known to be accessible to parasitoids or to those plants that had morphology conducive to nectar access by small wasps and 0 for those plants not fitting that description. I collected data on parasitoid diversity, abundance, richness, and parasitism rate. In this study there was no clear relationship between leafroller parasitism and either the broad seasonal variation in floral abundance or distance to linear habitat elements such as hedgerows. However, parasitoid abundance did differ by season; abundance was greater in the spring and early summer than later in the season. I found no correlation between the remotely sensed and field based

landscape metrics to each other or to parasitoid abundance or diversity. The relative lack of spatial and temporal variation in floral abundance is reflected in a similar lack of variation in parasitoid diversity and richness. I determined that it is possible to calculate landscape metrics using remotely sensed data; however, the resolution of the datasets inhibits the scale at which these metrics might predict landscape heterogeneity; if parasitoids are responding to metrics at finer scales the resolution of these datasets may not be fine enough to pick up on these differences. It is also possible that parasitoids might interact with their landscape at scales larger than the extent of this particular farm, or may be responding to variables I did not test here.

Keywords: Parasitoid, Leafroller, Floral resources, Caneberry, Landscape structure, Diversity

INTRODUCTION

Agricultural landscapes are inherently less complex and more disturbed than their more natural counterparts. These disturbances can result in an environment that is hostile to insects in general and to parasitoid wasps in particular. The biological control provided by parasitoid wasps is often severely limited in agricultural landscapes (Suh et al. 2000, Bianchi et al. 2006, Chaplin-Kramer et al. 2011). A number of factors have been proposed to explain this limitation; these include high pesticide use, high rates of disturbance, habitat fragmentation, and reduced abundance or diversity of floral resources in agricultural landscapes (Heimpel and Jervis 2005, Thies and Tscharntke 2005, Tscharnke et al. 2005). Landscapes provide natural enemies varied habitat elements: nesting sites, microclimates that prevent desiccation during the heat of the day, refuge from pesticide sprays and other farm related disturbances, food, and alternate hosts. Adult parasitoids in particular need access to a nectar source in order to effectively search for hosts and to mature or increase their egg loads. A number of studies have shown that parasitoids exhibit increased longevity and fecundity when allowed ample access

to floral resources, which in turn can result in higher parasitism rates (Begum et al. 2006, Lee and Heimpel 2005, Winkler et al. 2006, Lavendero et al. 2006, Rebek et al. 2005). Recent experiments have shown that starved parasitoids respond to food and host cues differently than wasps that are not starved (Lewis & Takasu 1990, Jacob and Evans 2001, Lightle et al. 2010). Wasps that are lacking food will choose food cues over host cues, whereas wasps that are not starved will choose host cues (Lewis & Takasu 1990, Jacob and Evans 2001, Lightle et al. 2010). The link between floral resources and parasitoid abundance and behavior forms part of the rationale for conservation biocontrol strategies that seek to enhance habitat conditions for natural enemies within agricultural landscapes (Landis et al. 2000). Effectively implementing these strategies requires a detailed understanding of how floral resources and other habitat factors vary within particular landscapes, and how these patterns influence the demographic traits and behavior of specific predator-prey species complexes (Landis et al. 2005, Wilkinson and Landis 2005). Yet, surprisingly few studies have comprehensively documented the spatial and temporal patterns of floral and other habitat resources available to parasitoids within agricultural landscapes.

One complexity that is often not addressed in studies is that flowers can vary greatly in the quality of the resources they provide parasitoids. Some plant species produce little or no floral nectar, produce nectar of relatively poor nutritional value, or have flowers with long or complicated corollas that can limit nectar availability for small wasps and other short mouthed insects (Baggen et al. 1999, Arévalo and Frank 2005, Koptur 2005, Russell 2013). Most studies do not screen for floral suitability, and those that do typically describe floral resources at limited temporal or spatial scales. However, agricultural landscapes can include a range of diverse floral types that vary in their spatial arrangement relative to crop fields as well as their flowering phenology, and this could potentially influence the biocontrol efficacy of parasitoids (Gurr et al.1998, Tscharntke et al. 2005b, Vollhardt et al. 2010).

Floral resources are not the only habitat element required by parasitoids. The structural components of vegetation provide preferred microclimates and refuges from disturbances such as pesticide sprays (Kawai 1997, Landis et al. 2000, Marshall and Moonen 2002, Smith et al. 1996). Overall, insect diversity tends to increase with vegetation diversity and structural complexity (Bianchi et al. 2006, Esch et al. 2005, Marshall and Moonen 2002). Most studies investigating parasitoid activity in agricultural landscapes do not directly evaluate structural habitat characteristics. Instead, most assume that structural habitat components that are beneficial to parasitoids are associated with less disturbed and less intensively managed habitat types, or with broad measures of vegetation heterogeneity. In most studies these are defined even more broadly as percent non-crop or natural area surrounding a farm, or as a measure of landscape heterogeneity surrounding a farm (Chaplin-Kramer 2011 and references within). High proportions of non-crop and less intensively managed vegetation have been associated with an increased abundance of beneficial insects and pest control (Tscharntke 2005). A recent review of these studies found that the best predictor of parasitoid activity on farms was the percent natural area surrounding farms (Kreman and Chaplin-Kramer 2011). However, both structural complexity and floral resource abundance potentially covary with broad vegetation classifications such as non-crop area, and it is not clear what the relative importance of each is to parasitoid activity.

Highly mobile insects such as parasitoids can potentially interact with habitat elements over a range of spatial scales, and this is a third broad complexity that complicates predicting parasitoid activity within a particular agricultural landscape. Insects of higher trophic levels are predicted to be more adversely affected by habitat fragmentation than those below them on the food web; an effect that is especially pronounced in those insects that have small body sizes, are resource specialists, and have low dispersal abilities (Holt et al. 1999, Kruess and Tscharntke 1994). Individual species and species groups can often have specific scale dependent responses to habitat conditions. For instance, the activity of

generalist natural enemies is often positively associated with increased landscape complexity at all spatial scales, whereas the activity of specialist natural enemies tends to be associated more strongly with habitat conditions at smaller spatial scales (Chaplin-Kramer et al. 2011).

HABITAT FOR PARASITOIDS IN CANEBERRY PRODUCTION SYSTEMS

Most of the literature describing landscape habitat conditions for parasitoids in agricultural systems comes from annual cropping systems; there is comparatively little information describing conditions in perennial cropping systems (Kreman and Chaplin-Kramer 2007). Perennial systems could differ considerably in both the abundance and timing of the resources they provide parasitoids. Compared to many annual systems perennial systems may provide considerable floral resources throughout the year both from the crops themselves (e.g. fruits and berries) and from non-crop plants in less intensively managed inter-rows and field margins. Perennial systems may also provide much improved structural habitat conditions relative to annual systems.

Caneberry production is a thriving business in the Pacific Northwest region of the United States. Oregon alone accounts for 90% of US blackberry production and 10% of raspberry production; Willamette Valley farms grow the bulk of these percentages (Washington & Oregon Caneberry PMSP 2003). In 2011, these markets represented 57 million dollars in value for Oregon growers (NASS/USDA 2011). Berries that are destined for fresh or individually quick frozen (IQF) markets have zero tolerance for contaminants. Pre-harvest "clean-up" pesticide sprays are currently being used to control the key contaminant pest in processed caneberries, a leaf roller known as the orange tortrix *Argyrotaenia franciscana* (Walsingham) (formerly *Argyrotaenia citrana* Fernald) (Lepidoptera: Tortricidae). However, these sprays are a costly and sometimes ineffective means of control, and they may be inordinately harming beneficial insects and thereby inadvertently making the pest problem worse (Jepson pers. com. 2013).

There are several parasitoid wasps that attack orange tortrix; the most common one is *Apanteles aristoteliae* (Knight and Croft 1987, Walker and Welter

2004, Bolda et al. 2010). *A. aristoteliae* is a solitary koinobiont (allowing the development of its host while feeding) endoparasitoid that is the key parasitoid of leafroller pests in a number of other important crops like apples and grapes (Basinger 1938, Kido et al. 1981, Coop et al. 1989, Walker & Welter 2004). Biological information on *A. aristoteliae* is largely lacking in the literature; however, it is known that adult *A. aristoteliae* do not host feed (Lightle et al. 2010). Therefore, the wasp likely extends its life span and fecundity via nectar feeding (Lightle et al. 2010). This suggests that improvements to floral resource availability on farms could enhance *A. aristoteliae* activity and biological control. However, currently very little is known about how floral resources for *A. aristoteliae* and other parasitoids vary temporally and spatially within typical caneberry production systems or the degree to which parasitoid activity covary with these patterns. Unfortunately, there exists a very poor understanding on how structural habitat components relate to patterns of floral abundance and parasitoid activity.

OBJECTIVES

The objectives for this study were to: 1) describe the spatial and temporal patterns of floral resource availability for parasitoids at the local farm scale in a typical caneberry production system, 2) describe the degree to which patterns of floral resource abundance covary with fine scale vegetation structure, and 3) test the degree to which parasitoid abundance, diversity, and biocontrol activity covary with patterns of floral resource abundance, vegetation structure, and season. This study is unique in describing habitat conditions for parasitoids within a diverse perennial system. It also combines descriptions of vegetation structure derived from remotely sensed data with higher resolution field surveys.

MATERIALS AND METHODS

STUDY SITE

The study site was Oregon State University's Lewis Brown (LB) farm located in Corvallis Oregon (Figure 1). A variety of crops are grown at LB (e.g. vegetables, fruits, nursery plants, turf, etc.); this crop diversity makes LB characteristic of the many diversified small holding farms in the Willamette valley. LB farm is low input (e.g. low pesticide spray levels and toxicities), with approximately 8 % of the farm managed explicitly under organic production methods. There are two main caneberry fields at LB separated by approximately 300 meters. The larger field is located proximate to the explicitly organic area of the farm and is near a forested area and multiple mature hedgerows. The smaller field is located near the entrance to the farm adjacent to experimental blueberry fields, a gravel plant pad, unplanted tilled areas, and heavily mowed turf areas. These caneberries are grown for breeding purposes and as such the only farm management techniques they receive are occasional hand weeding in the rows and seasonal pruning and tying up of canes.

INSECT AND FLORAL RESOURCE SAMPLING

In the summer of 2011, I sampled the two caneberry fields for leafroller larvae using timed visual surveys. Surveys were conducted bi-weekly beginning the last week of April 2011 and lasted through the first week of October 2011, for a total of approximately 14 sample events.

Because rows of caneberries are of differing lengths, I used a 5 minute time limit per row in order to control for sampling effort. Leafroller larvae were brought back to the lab and kept alive on a diet formulated for lepidoptera until they pupated, died from an unknown cause, or parasitoids were reared out. All parasitoids and lepidoptera were identified to species.

For each caneberry field, bi-weekly floral surveys were done in rows and the area surrounding fields at four spatial scales with radii of 20, 50, 100 and 200 meters (Fig. 1). Sampling started in July and lasted until October for a total of 7 sample events. For every sample event, I estimated the percent areal cover of

open flowers for each plant species within 1 m^2 quadrats at 10 random sample points for each field and each buffer distance. Some plants, typically horticultural cultivars, were only identified to genus (e.g. for all caneberries I classified them as Rubus spp.). Each plant species encountered during the floral surveys was scored for its potential to supply nectar to foraging parasitoid wasps on a binary scale (high potential, low potential). Scores were derived from an extensive review and meta-analysis of the literature describing the behavioral and physiological responses of parasitoid wasps to flowers of different plant species (Russell 2013). I calculated a potential floral resource availability (PFRA) index for each field and buffer at each sample period by summing the percent floral cover for species that were classified as having a high potential to provide available nectar for parasitoids. The PFRA is an estimate of potential nectar availability. The actual nectar availability can also be influenced by site specific differences in nectar production by the plants, competition and facilitation from bees and other nectar feeders, and the presence of aphids or similar insects that produce sugars that some wasps can feed on.

LIDAR AND LANDCOVER DATA

I described vegetation structure within each buffer using a vegetation canopy model derived from LiDAR. The vegetation canopy model was built using the 2009 LiDAR highest hits returns collected and processed by Watershed Sciences Inc. for the Oregon Department of Geology and Mineral Industries (DOGAMI 2009). The resolution of the LiDAR dataset was ± 3 meters, and vertical accuracy was ± 37cm. As a way of classifying the structural complexity of vegetation canopy height, I reclassified the canopy layers into 18 separate height classes; each class representing a specific height range (Table 1). Because there are potentially more vegetation types of interest to us at lower vegetation heights (e.g. shrubs, weedy vegetation, hedgerows), I made our classification scheme more detailed at lower heights by making the classes represent smaller ranges of heights (Table 1).

Lewis Brown has several natural and man-made linear habitat features such as hedgerows that could represent particularly resource rich habitats. The caneberry fields at LB farm were at differing distances to these features. I used Spatial Analyst within ArcGIS 10 to calculate the distance from the center of each caneberry row to the center of the closest hedgerow to determine if there were any effects of distance to hedgerow on likelihood of leafroller larvae being parasitized (ESRI 2011).

All analysis of landcover and LiDAR data were done using ArcGIS 10.0 (ESRI 2011).

ANALYSIS

For each field, buffer distance, and sample period I estimated: 1) potential floral resource availability (PFRA) as described above, 2) floral richness and diversity, and 3) height class richness and diversity. All diversity estimates were made using Simpson's index (D) (Magurran 2004). Height class richness was calculated by summing the number of distinct height classes within each buffer. Diversity estimates were calculated from the areal proportional coverage of each height class within each buffer.

Because of high variability between sample dates in leafroller collections I grouped sample dates into two broad seasonal categories: Spring-Summer (April-August 8th) and Summer-Fall (August 22nd-October 11th) for all analyses involving leafroller collections.

The effect of distance from field centers (five levels) and season (two levels) on PFRA, floral richness, and floral diversity was tested using two-way ANOVA. The effect of season on total parasitoid abundance, richness, diversity, and field leafroller parasitism rate was tested using t-tests. The effect of distance to nearest hedgerow habitat on the likelihood that leafroller larvae were parasitized was tested using logistic regression. SYSTAT 12 was used for all statistical analysis (SYSTAT 2007).

RESULTS

PATTERNS OF FLORAL RESOURCE AVAILABILITY

The study farm supported a diverse range of plant species. The most dominant in terms of floral abundance included native plants (typically associated with hedgerow habitat), crops, and weedy species commonly found in agricultural landscapes (Table 2). The dominant floral cover differed between early and late season. Flowers of *Sambucus nigra* (Elderberry), a native shrub found in the hedgerows, and *Convulvus arvensis* (field bindweed), a common agricultural weed, were the most dominant with 19.71 and 11.84 percent floral bloom cover respectively, early in the season (Table 2). Two well-known agricultural weeds, *Veronica persica* (speedwell) and *Daucus carota* (Queen Anne's lace) had 13.13 and 12.89 percent bloom covers respectively late in season (Table 2). Field crops also contributed to bloom cover with potatoes in the spring and beans in the summer offering 5 percent bloom cover each. Across all sample dates, the mean floral richness was 11 ± 0.51, mean PFRA was 0.024 ± 0.004, and mean floral diversity was 1.77 ± 0.06 (N=35).

I found no significant effect of season, or distance from field center on the floral assemblage descriptors (Table 3). PFRA tended to be higher in the spring, but these differences were not statistically significant (Fig.2A and B, Table 3). Floral richness (FLRR) tended to be similar across dates and seasons and to fluctuate mildly across scales (Fig. 3A and B, Table 3). There was no overall significant main effect of season or scale on FLRR; however, there was a significant interaction of scale and season. FLRR differed by season at the 100m scale (Tukey's pairwise comparison $p = 0.044$), and differed by scale between 100 m and 200 m (Tukey's pairwise comparison $p = 0.040$) and between 20 m and 100 m (Tukey's pairwise comparison $p=0.040$) in spring (Table 3). Floral diversity tended to be similar by scale and date, with the exception of some higher diversity scores on the August 8th sample date (Fig. 4A and B). However, these differences were not statistically significant (Table 3). The mean abundance of flowers with high potential parasitoid suitability was always higher than those

with low potential suitability, with the exception of the August 22 sample date, where mean floral abundance was higher for those plants that had low potential suitability (Fig. 5A and B). The dominance of suitable floral types was especially marked in the early part of the season (Figure 5A and B). To test for correlation between PFRA and the metrics calculated from LiDAR, I calculated the mean PFRA (N=10) for each distance and each sample date paired with the corresponding LiDAR (N=2) metric for each distance. PFRA was not correlated with vegetation height class richness (R^2= 0.014, $F_{1, 25}$ =0.372, p = 0.547) or height class diversity (R^2= 0.014, $F_{1, 25}$ = 0.363, p = 0.552).

PATTERNS OF PARASITOID ABUNDANCE AND ACTIVITY

A total of 916 lepidoptera larvae were collected, out of which 150 parasitoids were reared. The parasitoid assemblage consisted of eight species in total (Fig. 6). The species composition of the assemblage was fairly consistent over the season although *Macro countrus* was only found early in the season and *Glypta varigata* was only found late in the season (Table 4.) These two species were very rare in our collections, representing one and two individuals respectively (Fig. 6). Mean leafroller parasitism rate across the entire season was 18.7 ± 2.2 percent (N=10). *Apantales aristoteliae* was the most common parasitoid species collected followed *by Oncophanes americanus* and *Meteorous argyrotania* (Fig.6).

There was a significant effect of season on parasitism rate (t (114) =2.419, p = 0.017) and on parasitoid abundance (t (114) =4.107, p = 0.00): mean parasitoid abundance was higher early in the season, while mean parasitism rate was higher later in the season (Fig. 6A and D.)

Parasitoid diversity tended to be higher early in the season, while parasitoid richness tended to be higher later in the season (Fig. 6B and C). However, no significant effect of season was found on either parasitoid richness (t (114) =0.19, p = 0.854) or diversity (t (114) =-1.198, p = 0.262).

The likelihood that leafroller larvae were parasitized was unrelated to its distance from a hedgerow habitat (Table 5).

CONCLUSIONS AND DISCUSSION

Lewis Brown farm has a rich mix of crops, planted habitat hedgerows, wooded areas, and weedy species that provide parasitoids with an abundance of floral resources. That these resources did not vary with distance from caneberry fields shows that floral resources are dispersed across the farm. In this study PFRA did not appreciably change with distance from crop fields. The floral resources in caneberry fields come from flowering caneberry plants as well as a mix of understory weeds and cover crops. Since this is a perennial berry cropping system, disturbances that might reduce PFRA (e.g. crop harvest and turnover) are minimized. Other, more intensive systems, where fields are harvested and plowed at least once a year, do not allow the buildup of weedy species that can make up large proportions of PFRA on farms (Weibull et al. 2000). This paucity of plant diversity within fields can reduce the effectiveness of natural enemies (Altieri et al.1993, Winkler et al. 2005). Perennial cropping systems have the ability to increase parasitoid colonization because they offer habitats that are more established and less ephemeral in nature than annual systems (Altieri et al. 1993). Another perennial vegetation type that provided significant floral resources was the planned hedgerows and unplanned woody borders. These included many plants that are known to be accessible and beneficial to parasitoids. In particular, *Holodiscus discolor* and *Sambucus nigra* contributed significantly to total floral abundance early in the season. Later in the season, flowering bean crops and weedy species made up a large proportion of bloom that is known to be accessible to parasitoids.

In this study parasitoid abundance was greater in the spring and early summer than later in the season. This pattern has been shown in Paoletti et al. (1997) where peak numbers of parasitoids were found in the spring. This mirrors the pattern in floral abundance that was similarly reduced in late summer relative to early in the season. Parasitoids utilize floral resources for nectar among other things, so it stands to reason that increases in floral abundance should correlate with increased parasitoid abundance. In fact, this has been the case in a number of

studies (Irvin 1999, Platt 1999, Stephens 1998). However, the pattern that I found was weak and could not directly be ascribed to floral phenology. It is possible that the patterns seen of increased parasitoid abundance in the early part of the season as well as the increased rates of parasitism later in the season are due to the biology of the parasitoids and their hosts and not the floral resources at LB.

In this study there was no clear relationship between leafroller parasitism and either the broad seasonal variation in floral abundance or distance to linear habitat elements such as hedgerows. Other research has found an effect of distance to hedgerow on parasitoid diversity and parasitism rates (Baggen and Gurr 1998, Paoletti et al.1997). However these effects were more pronounced in simplified landscapes, where parasitoids may be nectar limited. It is likely that the resources of the hedgerows at LB, while beneficial to the parasitoids, are only one of the many floral resources available, and as such parasitism is not contingent upon the hedgerow location. Alternatively, it is also possible that these parasitoids are highly vagile, and that the extent of our study was too small to detect any differences. That the caneberries themselves don't offer large amounts of bloom cover at LB farm, and what they do offer diminishes significantly later in the season, doesn't seem to affect overall parasitism rates or PFRA. This is likely due to the rich weedy plant community that grows within the lanes and rows of the caneberry fields. It is understood that parasitoids cannot access all flower types, however, it is unclear what the optimal amount and arrangement of the "right" kind of floral resources might be. One reason significant patterns may not have been seen is that floral resources at LB farm are significantly abundant and are evenly distributed spatially and temporally. In fact, our study showed that the majority of flowers at LB had a high potential to be utilized by *A. aristoteliae.*

I found no direct correlation between the remotely sensed vegetation height metrics and the field sampled metrics. Comparing results of landscape metrics from different studies is fraught with issues. Differences of scale (i.e. grain and extent of study area) can cause loss of information (e.g. rare groups can be lost at coarser resolutions) (Turner et al. 1990). Also, diversity values from

different taxonomic groups may not be correlated (Roschewitz et al. 2005). These issues may not allow a direct comparison between our remotely sensed and field collected metrics. The lack of correlation between our metrics from these two studies could be attributed to the particular remotely sensed landscape metrics I calculated poorly describing the landscape at the field scale. Other more detailed measurements, like field or patch edge shape and size, could also be calculated from the LiDAR and compared to field measurements. Using height class diversity to describe landscape complexity, as I did for this study, may not offer a detailed enough estimation of vegetation diversity. Other researchers have used the standard deviation of mean height as a measure of landscape heterogeneity (e.g. Mason et al. 2003) and have combined multispectral satellite imagery with the LiDAR to define vegetation type and percent vegetation cover.

The limited amount of spatial and temporal variation in floral resource abundance on this study farm seems related to the relatively diverse and complex vegetation of this perennial system. This relative lack of spatial and temporal variation in floral abundance is reflected in a similar lack of variation in parasitoid activity. However, an alternative explanation for the lack of variation observed in our study is that I have failed to adequately describe the most pertinent habitat drivers of parasitoid activity in this system. Parasitoids benefit from on farm perennial habitats that can offer food, shelter, and alternative hosts as well as shelter form agricultural disturbances. However, the interactions in these systems are very complex and it is possible that our sampling regime may very well have missed a variable that is actually driving parasitism rates. For example, intuitively I thought parasitism rate would increase with total larvae collected; however, I did not find this to be the case in this study. Parasitism rate did not increase with total number of larvae collected. In fact, an effect analogous to this has been documented by Walker & Welter (2004). In field trials, the rate of parasitism by *A. aristoteliae* remained at or near 40% regardless of host density (Walker and Welter 2005). In addition, the single season that this study describes is also a significant limitation that may hamper our ability to detect relationships

between resource patterns and parasitoid activity. Studies of multi-trophic interactions are greatly improved by data that not only span multiple spatial scales but also multiple temporal scales (Erlich and Murphy 1987, Thies et al. 2005, Wold-Burkness et al. 2005). Unfortunately, our findings are limited by the lack of this multi-year data.

Lewis Brown farm represents a diverse farming system that has a mix of perennial and annual crops, as well as significant areas of perennial non-crop habitat. This mix of habitats appears to be supporting relatively high floral resources season long across the entire farm. This in turn seems to support a healthy parasitoid community. This study site appears to be typical of caneberry farms in the Willamette Valley (See CH1), and perhaps typical of perennial systems in general, especially organic ones. Our study demonstrates that the resources that parasitoids can effectively utilize are present at LB farm and in greater abundance than those resources they cannot use; however I was unable to relate this to our calculated parasitoid metrics. Disentangling the relative importance of factors influencing the level of biocontrol in particular landscapes is complicated by the fact that many factors associated with agricultural intensification co-vary in space or time (Gabriel et al. 2006, Kremen et al. 2007, Boutin et al. 2008, Fahrig et al. 2011). This is likely the reason that very few studies have attempted to disentangled the influences of farm management and landscape factors (Schmidt et al. 2006, Veres et al. 2011). Future research should include attempts to link landscape patterns to functional diversity of both the plants (as they relate to insects) and the insects (as they relate to pest control). The use of remotely sensed data could allow landscape structure to be derived at large scales, potentially with low error. Coupling this information with strategically placed field based measurements or datasets with finer thematic resolution (e.g. Oregon GAP vegetation) could help increase the resolution of the datasets with reduced field time and at greater spatial scales.

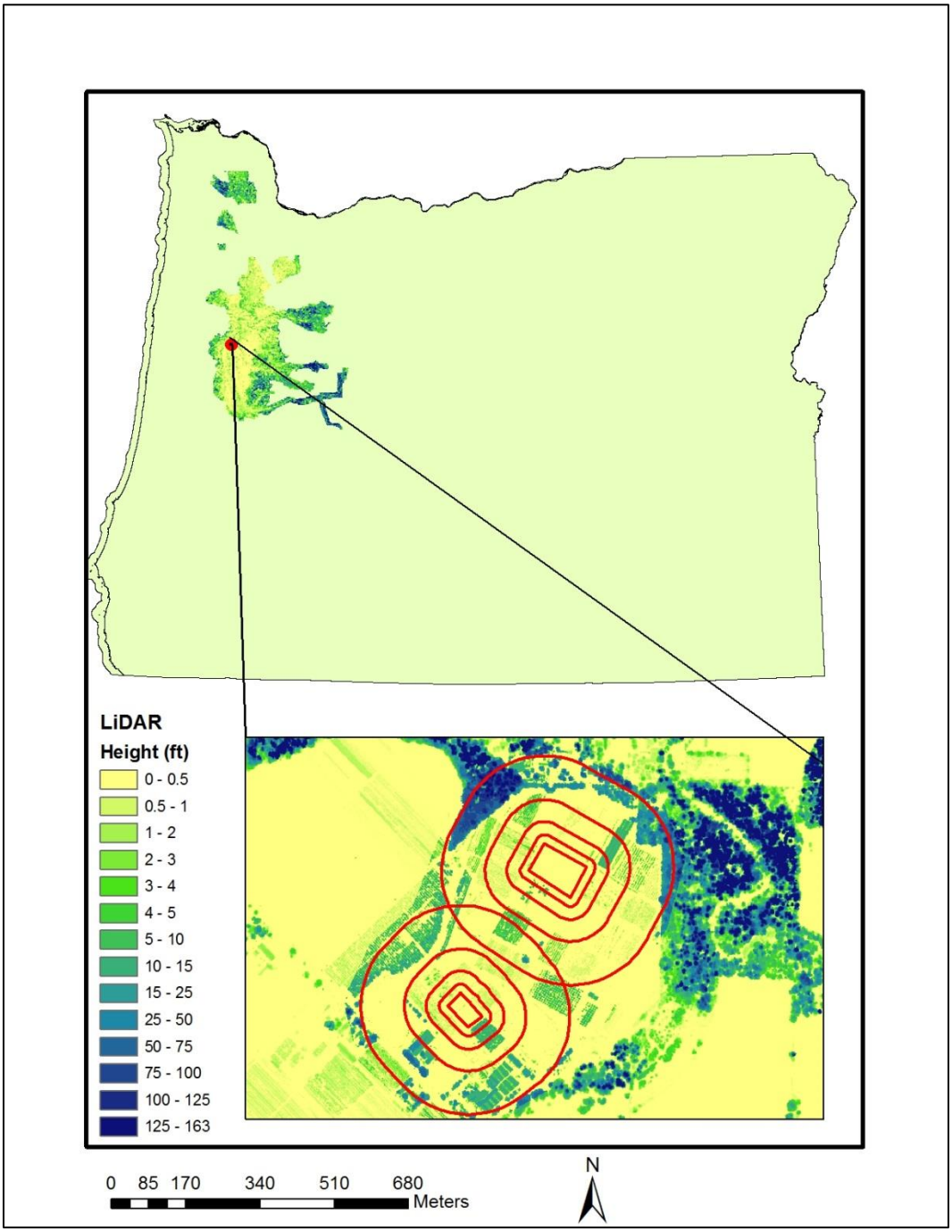

Figure 1. The study area is Oregon State University's Lewis Brown Farm, Corvallis, OR. Vegetation structure was classified within each caneberry fields and at 4 scales of 20, 50, 100, and 200 meters radii surrounding fields. Major vegetation types are shown based on a classification using LiDAR and ground surveys.

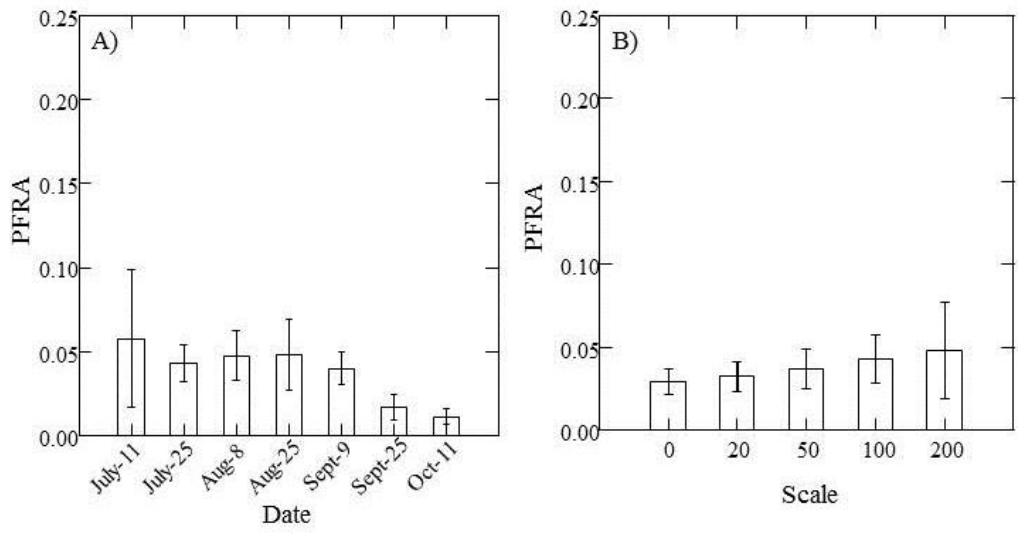

Figure 2. Patterns of mean potential floral resource abundance (PFRA) across sample dates (A) and distance from caneberry fields (B) on the Lewis Brown Farm, Corvallis OR. PFRA is estimated as the total % areal cover of open flowers that were determined to have high potential to provide nectar resources to parasitoid wasps as determined by referencing Russell (2013). Values are means ± SE of percent visual areal cover estimates within 1 m x 1 m quadrats. Quadrats were arrayed randomly within stratified blocks set at different distances from the center of two caneberry fields. N = 35 for A and B. All sampling was conducted in 2011. There was no significant effect of date ($F=1.01$, d.f. =6, $p=0.440$) or of scale ($F=1.092$, d.f. 1, $p=0.305$) on PFRA.

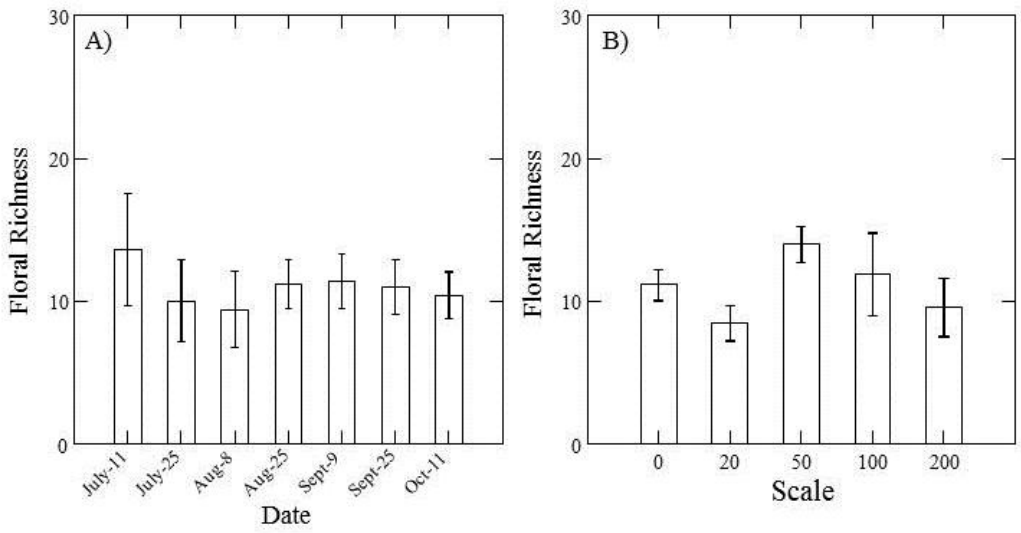

Figure 3. Patterns of mean floral species richness across sample dates (A) and distance from caneberry fields (B) Floral richness is estimated as the total number of species encountered. Values are means ± SE of total number of species within 1 m x 1 m quadrats. Quadrats were arrayed randomly within stratified blocks set at different distances from the center of two caneberry fields. N = 35 for A and B. All sampling was conducted in 2011. I found no significant effect of date ($F=0.365$, d.f. =6, $p=0.895$) or scale ($F=0.114$, d.f. 1, $p=0.739$).

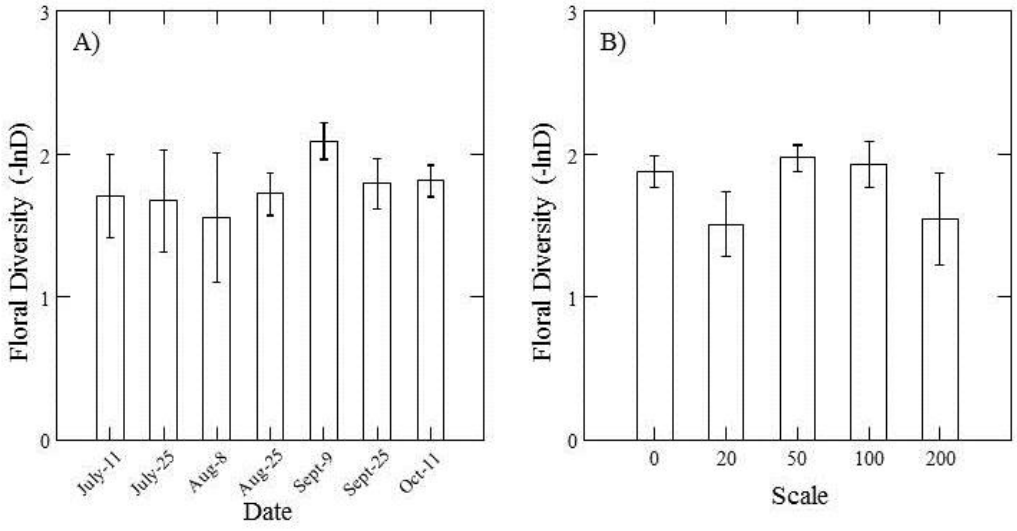

Figure 4. Patterns of mean floral diversity by sample date (A) and by distance from caneberry fields (B).Simpson's D index was used to calculated diversity; values were –ln transformed so that diversity increases as the value of D increases. Values are means ± SE of diversity scores calculated from areal proportional coverage of each plant species within 1 m x 1 m quadrats. Quadrats were arrayed randomly within stratified blocks set at different distances from the center of two caneberry fields. N = 35 for A and B. All sampling was conducted in 2011. No significant effect of date ($F=0.494$, d.f. =6, $p=0.807$) or scale ($F=0.502$, d.f. =1, $p=0.485$) was found.

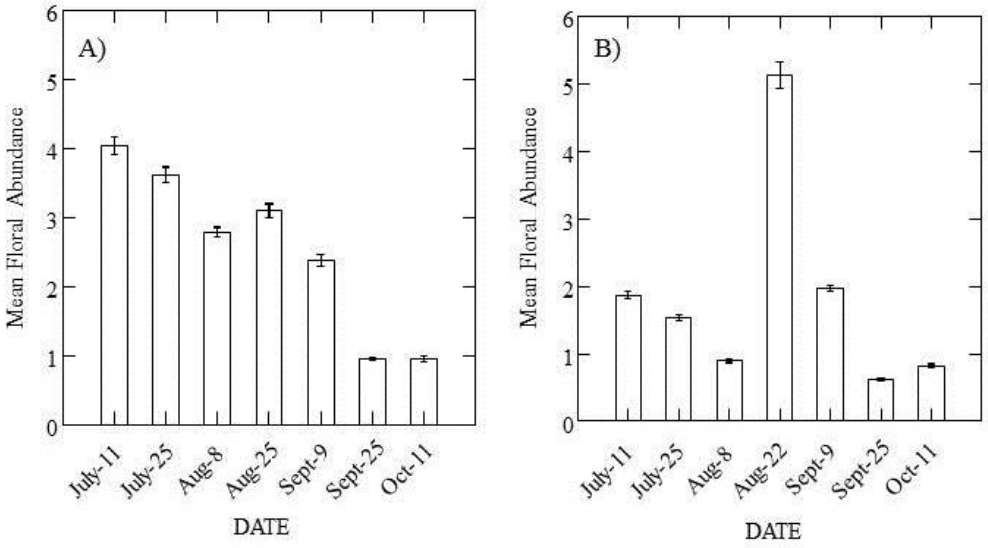

Figure 5. Mean percent bloom cover of flower types with high potential (A) and low potential (B) to provide accessible nectar resources for parasitoids. Values are means (N = 35) ± SE of percent visual areal cover estimates within 1 m x 1 m quadrats. Quadrates were arrayed randomly within stratified blocks set at different distances from the center of two caneberry fields on the Lewis Brown Farm, Corvallis OR.

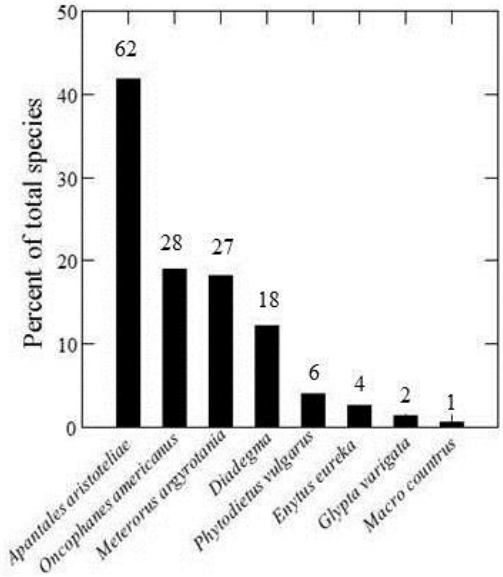

Figure 6. Relative species abundance of parasitoid species reared from leafroller larvae collected on Lewis Brown Farm, Corvallis Oregon from 2011. Numbers over bars are the absolute number of parasitoids reared of each species.

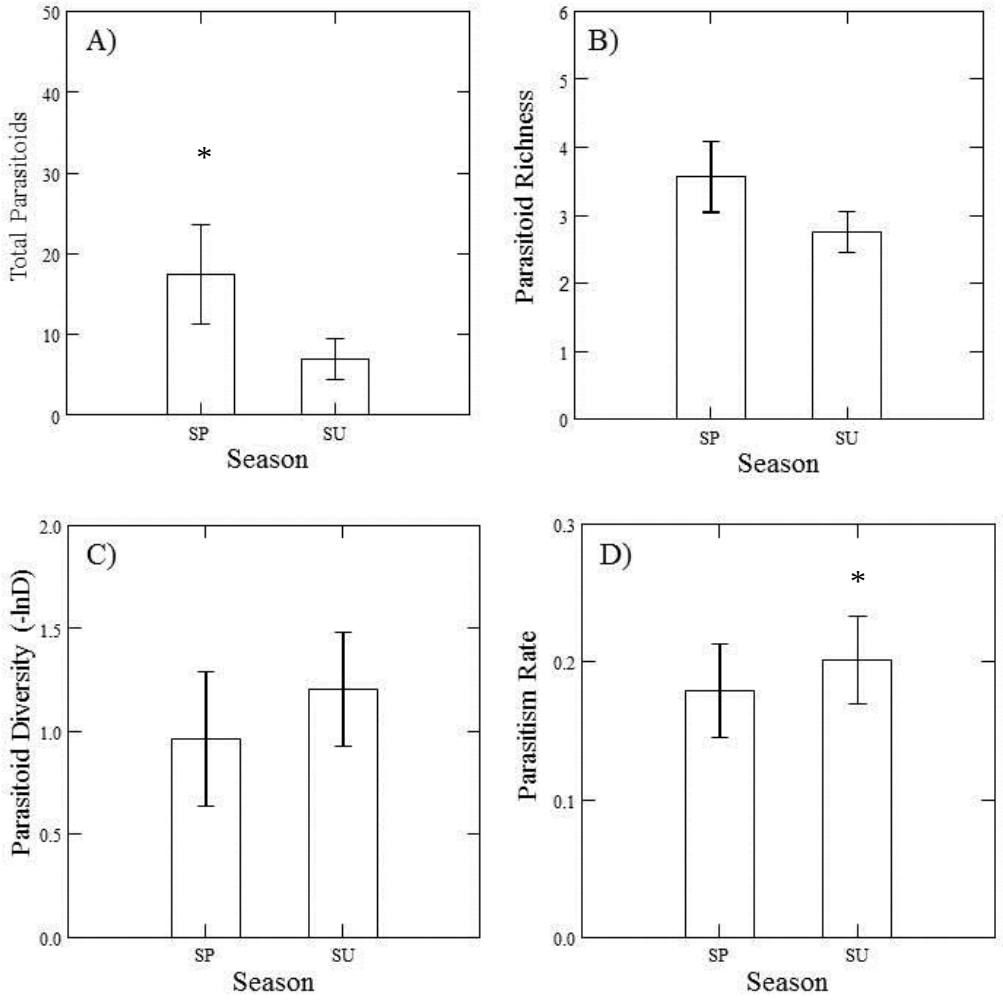

Figure 7. Mean parasitoid abundance (A) parasitoid species richness (B) parasitoid species diversity (C) and proportion of leafrollers parasitized (D) estimated from parasitoids reared from leafroller larvae collected on Lewis Brown Farm, Corvallis Oregon from April-October 2011. Values are means ± SE of each metric for spring (SP) leafroller collection dates (April –July 2011) and summer (SU) leafroller collection dates (August-October 2011). Diversity was estimated using Simpsons Index. N=58 for SP and SU. There was a significant effect of season on Parasitism rate ($t(114)=2.419, p=0.017$) and on parasitoid abundance ($t(114)=4.107$, $p=0.00$), but no significant effect of season on parasitoid richness ($t(114)=0.19$, $p=0.854$) or diversity ($t(114)=-1.198, p=0.262$).

Table 1. Vegetation canopy height class categories used in this study. The vegetation canopy model was derived from the highest hits LiDAR returns for the Willamette Valley (DOGAMI 2009). As a way of classifying the structural complexity of vegetation canopy height, I reclassified the LiDAR canopy layers into 18 separate height classes; each class representing a specific height range.

Height range (meters)	**Height Class**
0.15 - 0.30	1
0.30 - 0.61	2
0.61 - 0.91	3
0.91 - 1.22	4
1.22 - 1.52	5
1.52 - 3.05	6
3.05 - 4.57	7
4.57 - 9.14	8
9.14 - 15.24	9
15.24 - 22.86	10
22.86 - 30.48	11
30.48 - 38.10	12
38.10 - 44.20	13
44.20 - 50.29	14
50.29 - 56.39	15
56.39 - 68.58	16
68.58 - 85.34	17
85.34 – Max height	18

Table 2. The ten most abundant floral types, plus caneberries, on Lewis Brown Farm, Corvallis OR. Spring = July11 – August 8th and Summer = August 22nd - October 11th of 2011. Floral abundance was estimated as the total % areal cover of open flowers within 1 m x 1 m quadrats (N =35). Quadrats were arrayed randomly within stratified blocks set at different distances from the center of two caneberry fields.

Spring		Summer	
Species	Percent Bloom Cover	Species	Percent Bloom Cover
Sambucus nigra	19.71	*Veronica persica*	13.13
Convulvus arvensis	11.84	*Daucus carota*	12.89
Trifolium repens	7.92	*Trifolium repens*	6.67
Holodiscus discolor	7.56	*Amaranthus retroflexus*	6.25
Potatoes	5.55	Hypochaeris radicata	5.57
Hypericum perforatum	4.42	Beans	5.56
Prunus Vulgaris	4.30	Capsella bursa-pastoris	3.81
Rosa nutkana	4.25	Convulvus arvensis	3.56
Daucus carota	4.21	*Anthemis cotula*	3.13
Plantago lanceolata	3.91	*Atropa belladonna*	2.79
Caneberries	2.39	Caneberries	0.91

Table 3. Results of Floral resource metrics ANOVA. Potential floral resource availability (PFRA) and floral diversity are not significantly affected by season or scale. There is no overall effect of season or scale on floral richness; however, there was a significant interaction between season and scale: floral richness did differ between seasons at some scales (but not others) and between scales in some seasons (but not others).

	PFRA			Floral Richness			Floral Diversity		
	F	P	DF	F	P	DF	F	P	DF
Season	2.059	0.305	1	0	1	1	0.502	0.485	1
Scale	0.276	0.44	6	2.638	0.058	6	0.494	0.807	6
Season x Scale	0.156	0.958	4	4.215	0.01	4	2.732	0.052	4

Table 4. Seasonal variation in parasitoid species reared from leafroller larvae collected from Lewis Brown Farm, Corvallis OR from 2011.

Sample Date	Species
5/3/2011	*Apanteles aristoteliae* *Diadegma* *Oncophanes americanus* *Phytodietus vulgarus*
6/13/2011	*Apanteles aristoteliae* *Oncophanes americanus* *Phytodietus vulgarus*
6/28/2011	*Apanteles aristoteliae*
7/11/2011	*Apanteles aristoteliae* *Diadegma* *Enytus eureka* *Meterorus argyrotania*
7/25/2011	*Apanteles aristoteliae* *Diadegma* *Meterorus argyrotania* *Oncophanes americanus*
8/8/2011	*Apanteles aristoteliae* *Diadegma* *Macro countrus* *Oncophanes americanus* *Phytodietus vulgarus*
8/24/2011	*Diadegma* *Glypta varigata* *Oncophanes americanus*
9/9/2011	*Apanteles aristoteliae* *Diadegma* *Oncophanes americanus*
9/26/2011	*Enytus eureka* *Oncophanes americanus* *Phytodietus vulgarus*
10/10/2011	*Apanteles aristoteliae* *Oncophanes americanus*

Table 5.Logistic regression for test of effect of distance to hedgerow on likelihood of being parasitized.

Predictor	ß	Seß	z	p	$e^{ß}$
Constant	-2.285	0.739	-3.092	0.002	NA
Distance to hedge	0.005	0.005	0.86	0.39	1.005

Chapter 4

GENERAL CONCLUSION AND DISCUSSION

Parasitoids need nectar from floral resources in order to increase longevity and fecundity. However, research that directly connects landscape pattern to natural enemy mediated processes like pest control is lacking. Long term, large scale studies involving parasitoid, host, and habitat interactions are needed to better explain these connections. Increased attention to how pesticide use affects beneficial organisms and a growing market for organic produce may facilitate these types of studies.

Parasitoids benefit from on farm perennial habitats that can offer food, and alternative hosts, as well as shelter form agricultural disturbances. However, the interactions in these systems are very complex and it is possible that our sampling regime may very well have missed a variable that is actually driving parasitism rates. This study of twenty-four organic and conventional caneberry farms, located in Washington and Oregon, showed that organic and conventional caneberry farms were very similar in habitat composition across a range of spatial scales. The only differences found between these farms was at the very large (i.e. 5km) or very small (i.e. >0.05km) scales. However, these differences were not correlated to parasitism rates. Instead, farm practices that are unrelated to these habitat metrics seem to drive the observed differences in parasitism levels. A likely driver is the heavy use of insecticides, many of which are relatively broad spectrum, on the conventional farms in this study (Jepson pers. comm. 2013). A number of studies have documented the strong impacts that pesticide use can have on parasitoid populations (Brunner et al. 2000, Desneux et al. 2007, Rebek and Sadof 2003). However, effects on parasitism rate might also be attributable to other variables that I did not describe here, or that insects interact with at finer resolutions then I studied here. For instance, field level disturbances like tillage patterns and pesticide spray regimes can strongly influence plant community composition, and thus parasitoid effectiveness, at the local field scale (Anderson

1990, Tscharntke 2005). It is also possible that these farms are embedded in landscapes with very similar levels of structural complexity, which might impede our ability to detect differences between farm types. It could also be that any effects of landscape structure on parasitism rates are happening at a much larger temporal scale than I have studied here. Insect populations are also known to vary from year to year, and in order to better describe multi-trophic interactions, data need to be collected not only across multiple spatial scales, but also across multiple temporal scales (Thies et al. 2005). Unfortunately, our findings for Lewis Brown farm are limited by the lack of this multi-year data, and it may be that the four years of collected parasitoid data in used in chapter 2 is even insufficient (Erlich and Murphy 1987, Wold-Burkness et al. 2005).

Comparing results of landscape metrics from different studies is fraught with issues. Differences of scale (i.e. grain and extent of study area) can cause loss of information (e.g. rare groups can be lost at coarser resolutions) (Turner et al. 1990). Also, diversity values from different taxonomic groups may not be correlated (Roschewitz et al. 2005). These issues may not allow a direct comparison between our remotely sensed and field collected metrics. The lack of correlation between our metrics from these two studies could be attributed to the particular remotely sensed landscape metrics I calculated poorly describing the landscape at the field scale. Other more detailed measurements, like field or patch edge shape and size, could also be calculated from the LiDAR and compared to field measurements. Using height class diversity to describe landscape complexity, as I did for this study, may not offer a detailed enough estimation of vegetation diversity. Other researchers have used the standard deviation of mean height as a measure of landscape heterogeneity (e.g. Mason et al. 2003) and have combined multispectral satellite imagery with the LiDAR to define vegetation type and percent vegetation cover.

The flora that makes up a landscape may or may not be appropriate as a resource for parasitoids, and thus might not be used by them. Our study demonstrates that the resources that parasitoids can effectively utilize are present

at LB farm and in greater abundance than those resources they cannot use; however I was unable to relate this to our calculated parasitoid metrics. Disentangling the relative importance of factors influencing the level of biocontrol in particular landscapes is complicated by the fact that many factors associated with agricultural intensification co-vary in space or time (Gabriel et al. 2006, Kremen et al. 2007, Boutin et al. 2008, Fahrig et al. 2011). This is likely the reason that very few studies have attempted to disentangled the influences of farm management and landscape factors (Schmidt et al. 2006, Veres et al. 2011). Future research should include attempts to link landscape patterns to functional diversity of both the plants (as they relate to insects) and the insects (as they relate to pest control). The use of remotely sensed data could allow landscape structure to be derived at large scales, potentially with low error. Coupling this information with strategically placed field based measurements or datasets with finer thematic resolution (e.g. Oregon GAP vegetation) could help increase the resolution of the datasets with reduced field time and at greater spatial scales.

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